Sustained Attention Lapses and Behavioural Microsleeps During Tracking, Psychomotor Vigilance, and Dual Tasks

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Abstract

Momentary lapses of responsiveness frequently impair vigilance and sustained goal-directed behaviour, sometimes with serious consequences. The literature underpinning research into lapses of responsiveness has generally referred to these lapses as sustained attention lapses. Currently, this literature is divided between two competing theories. On one hand, there is the mindlessness theory and, on the other, the resource depletion theory. Mindlessness theorists propose that sustained attention lapses result from the subject disengaging from sustained tasks due to their monotony and low exogenous support for attention. Conversely, the resource depletion theorists propose that sustained attention lapses arise because demands for endogenus attentional resources outstrip supply, which leads to substantially delayed response and/or errors.

In the present study, the predictions from the mindlessness and resource depletion theories were investigated by contrasting performance on attention tasks that differed in cognitive workloads. In the lesser demanding task, participants performed a simple psychomotor vigilance test (PVT). In the more demanding task, the PVT was undertaken concurrently with a continuous tracking task. The higher workload imposed by the dual task should reduce task monotony and the higher attentional requirement should increase the demand for attentional resources. If the mindlessness theory is correct the dual task should result in improved vigilance and reduce sustained attention lapses. If the resource theory is correct, the added attentional demand in the dual task should decrease vigilance and increase sustained attention lapses.

However, there are other types of lapses that the literature has not always clearly separated from lapses of sustained attention. One such lapse is the microsleep. Microsleeps are brief periods of non-responsiveness (0.5–15 s) associated with overt signs of drowsiness. The two theories of vigilance impairment provide contrasting explanations in the traditional vigilance literature, but neither theory addresses lapses due to microsleep events, which remains largely ignored.

Microsleeps are thought to emanate from a homeostatic drive for sleep/rest and a complex interaction between the brain's arousal and attention systems and, therefore, depend on the type of task being undertaken to modulate propensity for microsleeps. For example, a more demanding and engaging task should counteract the homeostatic drive for sleep and rest by increasing arousal. If true, tasks that increase cognitive workloads may lead to a reduction in microsleeping propensity.

We aimed to test the proposal that microsleep propensity is mediated by task by including in our study a continuous tracking task, which has previously been shown to elicit microsleeps. This task may, because of its consistency and repetitiveness, be considered a boring task. Moreover, it lacks any sudden stimulus

onsets and, therefore, can be considered a less engaging task than the dual-task, which features sudden onsets. If more microsleeps were found in the tracking task compared to the dual task this would provide support for the proposition that a task-generated increase in mindlessness would increase microsleep rates. Conversely, if more microsleeps occur during the dual-task, then this suggests that factors other than mindlessness influence microsleeping.

Twenty-three non-sleep deprived participants – 12 females and 11 males – with an average age of 26.3 years (range 21–40 years) and an average Epworth Sleepiness Score of 5.1 (range 0–10), completed the tasks during the early afternoon. They completed the two different tasks separately and concurrently (as a dual task), with the three conditions presented in a counterbalanced order. The PVT task was an extended 30-min version of the standard 10-min PVT used in many vigilance studies to match the duration of the continuous tracking task. In this task, the participant had to respond to a discrete randomly-presented visual stimulus. As per convention, failure to respond within 500 ms constituted an attention lapse. The 30-min continuous tracking task required the participant to use a floor-mounted joystick, to monitor and track a target randomly-moving on a computer screen. In this second task, lapses show as periods of flat tracking that, when associated with overt signs of sleepiness and at least 80 % partial eye-closure, are classified as microsleeps. The dual task was the PVT and tracking tasks being undertaken concurrently.

Both sustained attention lapses and microsleep rates were affected by task differences. Using only the results from participants who had at least one sustained attention lapse in either the PVT or dual task (N = 23), it was found that a participant was more likely to experience a sustained attention lapse during the more demanding dual task then the PVT task (median 15 vs. 3; range 1–74 vs. 0–76, Wilcoxon $z = 3.7$, $p = .001$). Conversely, of those participants who had at least one microsleep in either the tracking or dual task (N = 12), they were more likely to experience a microsleep during the more monotonous tracking task than the dual task (median 0 vs. 0; range 0–18 vs. 0–1, Wilcoxon $z = 2.3$, $p = .022$). Time-on-task also had an effect. Sustained attention lapses increased with time-on-task during the PVT task and dual task ($\chi^2_{5, N\,23} = 48.69$, $p = .001$; and $\chi^2_{5, N\,23} = 16.33$, $p = .006$ respectively). Moreover, sustained attention lapses increased at a greater rate during the more cognitively demanding dual task ($F_{5, 264} = 4.02$, $p = .002$). Microsleeps also increased with time-on-task, but only during the tracking task and not during the dual task $\chi^2_{2, N\,23} = 6.72$, $p = .035$).

The pattern of results supports the resource depletion theory over the mindlessness theory. When the cognitive workload increased, sustained attention lapses were more frequent. Conversely, the results also demonstrated that when the cognitive workload was decreased, the risk of lapsing due to microsleeps increased. Clarifying this relationship between cognitive workload and two types of lapses of responsiveness, sustained attention lapses and microsleeps, is important if we are to avoid inadvertently

increasing lapses of responsiveness. Both sustained attention lapses and microsleeps can have serious real-life consequences and, therefore, any contribution towards a potent, preventative strategy is important.

Acknowledgements

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I must also recognise the considerable contribution made by those patient souls who volunteered for this study. Without people who are prepared to put their hand up when asked to participate in these studies, meaningful research would be limited. I asked a lot from those who participated. They had to refrain from coffee, allow electrodes to be placed in their hair, and be subjected to a gruelling 90 min of testing. That they allowed me to do that was an extraordinary act of selflessness that on behalf of the sciences I applaud.

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Finally, I must recognise the encouragement, contribution, and sacrifice made by my wife Raewyn throughout the course of my studies. Without her unwavering support and tolerance, this study would not have been possible. Her belief in me at all times has been remarkable. Thank-you love.

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Table of Abbreviations

ACh	Acetylcholine
ARCES	Attention-related cognitive errors scale
BF	Basal fore brain
BOLD	Blood oxygen level dependent
CFQ	Cognitive factors questionnaire
DA	Dopamine
DMN	Default mode network
EEG	Electroencephalogram
EOG	Electro-ocularography
fMRI	Functional magnetic resonance imaging
GABA	γ-aminobutyric acid
His	Histamine
Lapse	Lapses of responsiveness
LTD	Laterodorsal tegmental nuclei
MCH	Melanin concentrating hormone
NIRS	Near infra-red spectroscopy
NREMS	Non-rapid eye movement sleep
N1	Stage 1 NREMS
N2	Stage 2 NREMS
N3	Stage 3 NRMS
ORX	Orexin
PPT	Pedunculopontine tegmental nuclei
PVT	Psychomotor vigilance task
REM	Rapid eye movement sleep
RT	Reaction times
SART	Sustained attention of response task
SCN	Suprachiasmatic nucleus
TCD	Transcranial Doppler sonography
TLX	NASA task load index
TMN	Tuberomammillary nucleus
TUT	Task unrelated thought
VLPO	Ventrolateral preoptic nucleus

Chapter 1. Introduction

Intrusive and unwanted lapses of responsiveness often occur in the real world despite the robust nature of human information processing (Moller, Kayumov, Bulmash, Nhan, & Shapiro, 2006). Typically, the outcomes of these lapses are trivial, but they can be of particular concern in some situations. In occupations where safety depends on extended periods of unimpaired performance, lapses can lead to severe outcomes. For example, 7–10% of the social cost incurred in 2008 for all New Zealand road crashes has been attributed to diverted attention or inattention (Ministry of Transport NZ). Unfortunately, even with the best of intentions, remaining alert can be difficult. There can be times when we find ourselves distracted, lacking motivation, and energy, perhaps even struggling to stay awake. It is often during those times that lapses of responsiveness occur (Esterman, Noonan, Rosenberg, & Degutis, 2012; Peiris, Jones, Davidson, Carroll, & Bones, 2006b; Poudel, Innes, Bones, Watts, & Jones, In Press).

It has been noted that, if left unchecked, the frequency of lapses of responsiveness leading to severe outcomes is likely to increase. Hancock said recently with respect to attention (2013, p. 98), "The phenomenal growth in the contribution of automation to virtually all realms of human work continues unabated …". The consequence of automation is sustained monitoring, which can be both attentionally demanding and de-arousing (Davies & Parasuraman, 1982). This, should it occur, can lead to task dis-engagement (Helton, Shaw, Warm, Matthews, & Hancock, 2008) and, consequently errors.

Therefore, elucidating and understanding these constructs in terms of task challenges is an important topic of research, not only because of the increased risk that comes with increased frequency, but also because of the risk from serious real-world consequences. For example, an air traffic controller who fails to respond to flights on converging tracks may precipitate a human tragedy (Shappell et al., 2006). A late night truck driver may drift across the centreline into the path of an oncoming car, or a security guard monitoring a security x-ray machine may miss an obvious sign of a terrorist act. There is a public expectation that such occurrences will be prevented, but that will only occur if the underlying causes of these lapses are clearly understood. Was the controller under-aroused or cognitively overloaded and/or mentally fatigued. Each of those two causal factors may require different solutions if the consequences are to be prevented.

The study of lapses began with the fathers of psychology Wilhelm Wundt (1832–1920) and William James (1842–1910) (see Figure 1-1) who both recognised attention as an important object of study. Subsequently, breakdowns in attention, have been investigated throughout the 20th century and into the 21st century (for example, Bills, 1931; Broadbent, 1953; Dinges & Powell, 1985; Helton & Carter, 2010; Innes et al., 2008; Jastrow, 1906; Mackworth, 1957; Manly, Robertson, Galloway, & Hawkins, 1999; Matthews et al., 1998; Parasuraman, Warm, & See, 1998; Peiris, Jones, Davidson, & Bones, 2006a; Reason, 1984; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1996). However, because the focus of many of these studies was largely sustained attention and vigilance, it appears that lapses associated with indications of sleep were, with the exception of the transport industry, mostly ignored. Furthermore, because the transport industry

was mainly concerned with the effects of fatigue, their emphasis was mainly on sleep-deprived participants (Anderson & Horne, 2006; Boyle, Tippin, Paul, & Rizzo, 2008; Harrison & Horne, 2000; Lim & Dinges, 2008; Moller, Kayumov, & Shapiro, 2003). It has only been in much more recent times that arousal-related studies have encompassed non-sleep deprived participants (Davidson, Jones, & Peiris, 2007; Innes, Poudel, Signal, & Jones, 2010; Peiris et al., 2006b; Poudel, Innes, & Jones, 2013; Poudel et al., In Press; Poudel et al., 2010).

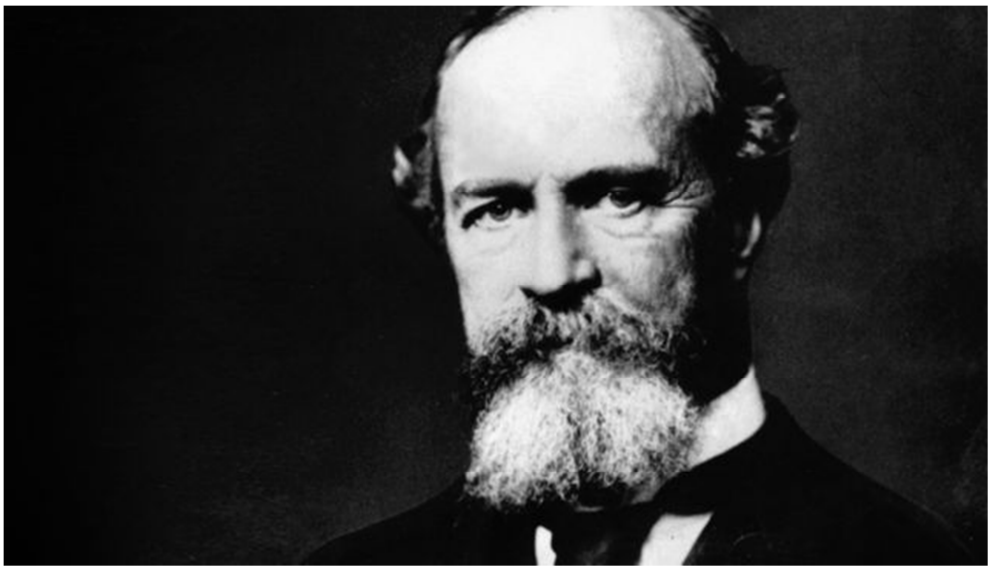

Figure 1-1 William James (1842 – 1920). Was considered to be one of the founding fathers of modern psychology, and was the author of Principles of Psychology, published in 1890. (Image from Philosophy and Philosophers, 2013)

Research has not been helped by the lack of a clear meaning for the various terms used in the literature. Researchers have used the terms 'behavioural microsleeps (BMs)', 'concentration lapses', 'EEG defined microsleeps', 'lapses', 'lapses of consciousness', 'lapses of responsiveness', 'microsleeps', and 'sustained attention lapses' synonymously, sometimes in reference to the same phenomena but often in reference to different phenomena. As a result there is no common understanding of the term (Anderson, Wales, & Horne, 2010; Boyle et al., 2008; Chee et al., 2008; Corfitsen, 1999; Moller et al., 2006; Moller et al., 2003; Parasuraman et al., 1998; Ruijter, Lorist, Snel, & De Ruiter, 2000). Accordingly, in this study we have followed the lead of Peiris and colleagues (2006) and have taken the term 'lapses of responsiveness' to be a super-ordinate term for two closely-related ephemeral phenomena: sustained attention lapses and behavioural microsleeps. These lapses of responsiveness, unlike behavioural arrests (Klemm, 2001), are considered to result from disruptions to executive functions, and arousal systems including the sleep/wake processes. They can manifest as: detection failures, delayed responses, response errors, and microsleeps (refer to Figure 1-2) (Carriere, Cheyne, & Smilek, 2008; Cheyne, Carriere, & Smilek, 2006; Dinges & Powell, 1985; Eagle & Robbins, 2003; Haider, Spong, & Lindsley, 1964; Helton, Kern, & Walker, 2009b; Manly et al., 1999; Poudel, Jones, Innes, & Bones, 2008b).

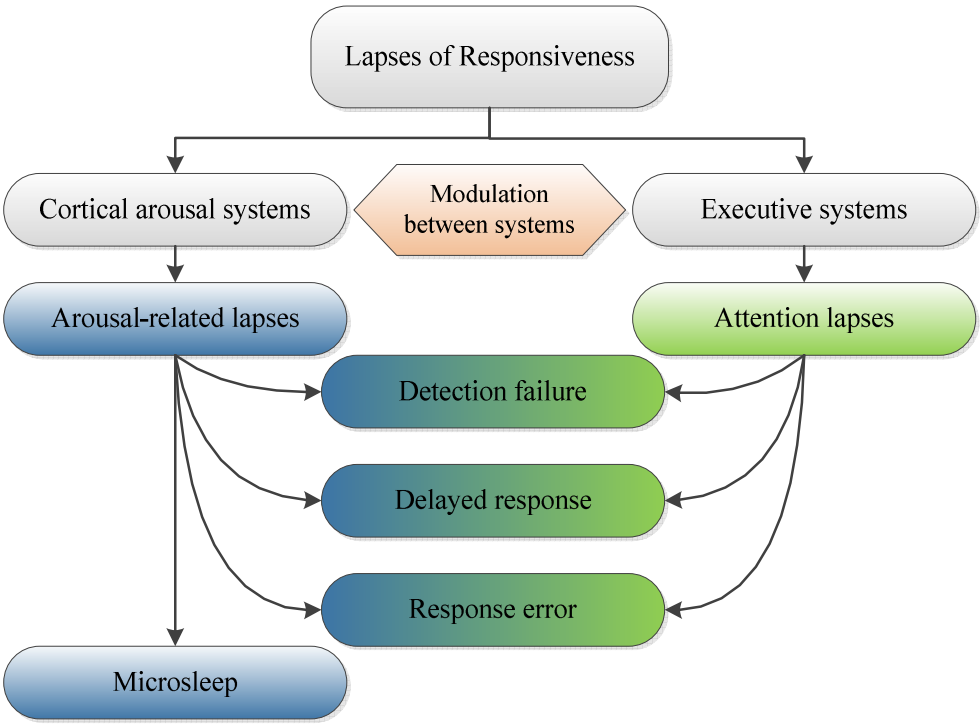

Figure 1-2 A hierarchical schematic of lapses. Lapses are categorized as being either mostly due to arousal or to executive systems although there is a reciprocal modulatory effect between them. Each category is further identified according to underlying behaviour and physiology. (Adapted from Poudel, 2010)

A microsleep is a brief episode of sleep, which may last from a fraction of a second up to 15 s. Although common in sleep- and non-sleep-deprived subjects (Peiris et al., 2006a; Poudel, Jones, & Innes, 2008a), complete agreement on how best to identify these episodes does not exist. Some studies have defined microsleeps according to behavioural characteristics (Adler & Kuskowski, 2003; Peiris et al., 2006a) while others have relied on EEG spectral, topographical, and morphological changes (Boyle et al., 2008; Harrison & Horne, 1996). In this study, we are interested in behavioural outcomes; therefore we have used overt indications of sleep including full or partial (greater than 80%) eye closure that overlaps with disrupted performance on a task to identify this ephemeral event. Consequently, it was not necessary that they be accompanied by 'an electroencephalograph theta burst in the absence of alpha activity' relied on by some to define microsleeps (Harrison & Horne, 2000; Williams, Granda, Jones, Lubin, & Armington, 1962).

Currently, research into sustained attention lapses, can be separated by two competing theories prominent in the vigilance literature: the mindlessness theory and the resource depletion theory. The mindlessness theory originates from Robertson and colleagues (Manly et al., 1999; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) who suggested that deficits in sustained attention are due to the features of mindlessness such as routinization, automaticity, and lapses of attentional focus brought about by reliance on exogenous stimuli. By way of contrast, proponents of the resource depletion theory attribute sustained attention

failures to a decline in available attention resources (Matthews & Davies, 2001; Warm & Dember, 1998). They theorize that cognitive resources are limited and continuous performance over time depletes the available pool necessitating an enforced brief respite (Grier et al., 2003; Helton et al., 2005; Helton & Warm, 2008; MacLean et al., 2009; Matthews et al., 2002a). This theoretical dichotomy is not particularly helpful. For instance, should cognitive workload be increased to relieve mindlessness, or will that exacerbate the problem of sustained attention lapses by increasing the demand for cognitive resources? Although each theory would suggest a different answer, both theories strongly link sustained attention lapses to the task being undertaken as is also the case for microsleeps. Microsleeps are theorised to be dependent on arousal levels that are mediated by task type. Although the two theories of lapses of sustained attention provide contrasting explanations in the traditional vigilance literature, neither theory addresses lapses due to microsleep events, which remains largely ignored.

Microsleeps are considered to be distinctly different from sustained attention lapses, both physiologically and behaviourally (Poudel, 2010). Nonetheless, they are far from being disassociated constructs. Microsleeps are thought to emanate from a homeostatic drive for sleep and a complex interaction between the brain's arousal and attention systems. This suggests that the type of task and cognitive workload it generates is likely to modulate propensity for microsleeps. For example, a number of studies have reported that lapses associated with homeostatic drive for sleep or rest and mediated by low levels of endogenous attention and exogenous stimulation have resulted in the onset of sleep (Chee et al., 2008; Dementienko et al., 2008; Harrison & Horne, 1996; Makeig & Jung, 1996; Matthews et al., 2002a; Moller et al., 2006). Given that both sustained attention lapses and microsleeps appear to be modulated by cognitive workload, it seems sensible to investigate the impact of cognitive workload on lapses.

Accordingly, the overall objective of this current work was to investigate the impact of cognitive workload on the two types of lapses: sustained attention lapses and microsleeps. It was considered that by comparing the frequency of sustained attention lapses during both relatively high and low cognitive workloads we would be able to contribute to the debate surrounding the two competing theories of sustained attention lapses. Furthermore, it was considered that by comparing the frequency of microsleeps during two contrasting cognitive workloads, we could empirically establish a relationship between the two constructs. With this in mind, the following key goals were identified:

1. Conduct a review of the literature pertaining to lapses in general but more particularly to sustained attention lapses and microsleeps;
2. Form hypotheses that relate cognitive workload to sustained attention lapses and to the two competing theories of sustained attention lapses, and to relate cognitive workload to microsleep frequency;
3. Complete an empirical test of the hypotheses;
4. Identify any shortcomings in the study; and
5. Propose future research.

Chapter 2. A Review: Lapses of Responsiveness

2.1 Chapter Overview

This chapter reviews the extant literature covering two important processes that when disrupted are thought to result in either of these two types of lapses of responsiveness: attention, and arousal processes including sleep/wake mechanisms. It begins by reviewing attention, with a particular emphasis on sustained attention before reviewing arousal. The link between arousal and sustained attention has been well established by the literature. Arousal is also axiomatic with sleep and the importance of the arousal system in the regulation of sleep is widely recognised. According to Bakotić and Radošević-Vidaček (2012) arousal is the third component along with the circadian system and the homeostatic system comprising the mechanism responsible for the regulation of sleep and possibly microsleeps. Finally this chapter is concluded with an examination of the literature surrounding microsleeps.

2.2 Attention

Attention was described by James (1907) as "the taking of possession by the mind in clear and vivid form out of what seem several simultaneous objects or train of thoughts". According to Stuss, Shallice, Alexander, and Picton (1995), this 'taking possession of the mind' is utilized to: sustain, concentrate, share, suppress, switch, prepare and set attention and perhaps is best summed by Norman and Shallice (1986, p. 3) who saw its primary purpose as "the control of action". Although sometimes conflated with consciousness, attention is considered to be a distinct process (Koch & Tsuchiya, 2007) but not a unitary one (McAvinue et al., 2012; Posner, 2008) that, in its broadest application, is used to enhance the processing of information (Oken, Salinsky, & Elsas, 2006).

Although once considered to be a unitary construct, attention is now thought of as two distinct forms, each of which affects performance in very different ways (Norman & Shallice, 1986). The first form of attention is managed by what Norman and Shallice have called a contention scheduling mechanism. Its purpose is to manage various mental schemas. It is mainly reflexive and operates in an open-loop fashion, predominantly involving automatic processes, which is claimed to be susceptible to sleepiness and exogenous stimuli such as noise (Verwey & Zaidel, 2000). The second form is a supervisory attentional mechanism that acts in a more flexible but closed-loop action to bias the selection process (Norman & Shallice, 1986; Verwey & Zaidel, 2000). van Zomeren and Brouwer (1994) also proposed a bimodal model but unlike that of Norman and Shalice, van Zomeren and Brouwer divided the attentional system according to the intensity aspect of alertness and sustained attention, and to the selectivity aspects of focused and divided attention.

Posner (2008) proposed that attention consisted of three functionally different networks, each describing different neural pathways and involving separate neuromodulators: (1) an alerting network that functions to

achieve and maintain of a state of high sensitivity to incoming stimuli, (2) an orienting network that functions as a filter and selector of information from sensory input, (3) an executive control network that functions to resolve conflictions among thoughts, feelings, and responses. These networks, along with perception and working memory (Shalev, Ben-Simon, Mevorach, Cohen, & Tsal, 2011), collectively account for a set of cognitive operations that are presumed to take place between the onset of a stimulus and behavioural response. These operations are what Oken et al. (2006) have referred to as focused attention, divided attention, shifting of attention, and sustained attention and what Ballard (2001) referred to as selective attention, divided attention, focused attention, and sustained attention (see also Cohen, Sparling-Cohen, & O'Donnell, 1993). Selective attention is the process where one stimulus or set of stimuli is selectively and preferentially attended to instead of others. Divided attention is the process of allocating attention resources simultaneously to more than one stimulus. Conversely, focused attention is the process of attending to relevant stimuli while rejecting irrelevant stimuli or information. However, while selective attention, divided attention, and focused attention, including the executive control of attention, are all important correlates of performance, sustained attention is the attention process mostly linked to lapses of responsiveness and therefore is described in greater detail.

2.3 Sustained Attention

2.3.1 *Definitions of Sustained Attention*

Sustained attention has been variously described (Aue, Arruda, Kass, & Stanny, 2009; Ballard, 1996; Buehner, Krumm, Ziegler, & Pluecken, 2006; Davies & Parasuraman, 1982; Dinges & Powell, 1985; Grier et al., 2003; Langner & Eickhoff, 2012; Manly et al., 1999; Oken et al., 2006; Posner & Petersen, 1990; Stuss et al., 1995; Weissman, Roberts, Visscher, & Woldorff, 2006; Wilcock et al., 1989). However, largely it is agreed that sustained attention is the ability of monitors – be they observers, listeners (Seli, Cheyne, Barton, & Smilek, 2012a) or haptics (Esterman et al., 2012) – to maintain a state of alertness and response readiness to changes in stimuli that occur either infrequently, or at irregular intervals, or that are barely detectable. The phrase, to maintain a state of alertness and response readiness to changes, implies a pre-perception process, much in the manner of spatial attention that occurs while a subject waits for an appropriate stimulus (Padilla, Wood, Hale, & Knight, 2006). It could, in light of this description, be termed ‘temporal tonic alertness’ where the term ‘vigilance’ would not seem out of place (Oken et al., 2006). This, of course, would be a fundamental shift from the classic definition of attention by James that placed attention during the stimulus and post-stimulus periods. It is perhaps then, not surprising that other authors have gone beyond a state of vigilance per se to include perception and response in the construct (Cheyne et al., 2006; Cheyne, Solman, Carriere, & Smilek, 2009; Langner & Eickhoff, 2012; Matthews & Davies, 1998; Posner & Petersen, 1990; Weissman et al., 2006).

Weissman et al. (2006) proposed that the outcomes of sustained attention were high-quality perceptual representations that are fed forward to other brain regions responsible for the determination of behaviour. This is in line with the suggestion of Posner and Petersen (1990) that the outcomes of sustained attention are detected signals for focal processing and with Matthews and Davies (1998) who said that the primary concern of vigilance was the detection of stimulus change. It is also in keeping with Langner and Eickhoff's (2012) definition that the process (commonly referred to as sustained attention but which they refer to as vigilant attention) when applied to monotonous tasks, is the process of sustaining efficient conscious stimulus processing. In their work, stimulus processing was taken to mean "the simple detection or discrimination of stimuli, including a simple cognitive or motor response but excluding 'higher' attentional or executive functions such as spatial orienting, resolving interference, dividing attention, or selecting between several overt responses" (2012, p. 2). Ballard's (1996) construct of sustained attention also included perception and response. Ballard argued that the operations involved in sustained attention were: firstly, the establishment of focused attention, then, perception of stimuli, prediction of probable response outcomes, response selection, and initiation of motor programs.

Yet others have gone further and extended the construct to include response selection and maintenance of response (Cheyne et al., 2006; Cheyne et al., 2009; Manly et al., 1999; O'Connor, Robertson, & Levine, 2011; Parasuraman, 1979; Robertson et al., 1997; Stuss et al., 1995), with some authors including in this construct, the ongoing response monitoring (Aue et al., 2009; Grier et al., 2003; Stuss et al., 1995). In this regard, one of the more expansive definitions of sustained attention was proposed by Robertson et al. (1997). They initially defined sustained attention as the "ability to self-sustain mindful, conscious processing of stimuli whose repetitive, non-arousing qualities would otherwise lead to habituation and distraction to other stimuli" (1997, p. 747). However, in later papers (Robertson & Garavan, 2004; Robertson & O'Connell, 2010) this construct was renamed vigilant attention – to differentiate attention as 'selection and management of goals' from attention as 'vigilant alertness' – while sustained attention was taken to mean "the capacity to maintain accurate responding over time" (Robertson & O'Connell, 2010, p. 80).

Nonetheless, their definition of what is commonly referred to by the majority of literature as sustained attention, appears to have been motivated by significant, albeit weak, correlations ($r = -0.29$), between a test of sustained attention, referred to by the literature as the Sustained Attention to Response task (SART), and Broadbent's Cognitive Factors Questionnaire (CFQ) (1982). The SART, unlike conventional tests of sustained attention where the monitor must respond to a rare critical signal, requires the monitor to respond to frequent signals and to withhold their response to a rare critical signal.

Robertson and colleagues' definition implies that a person's capacity for volitionally exerted control over attention is mediated by the strength of exogenous stimuli, which in turn is governed by the novelty and saliency of the stimulus. Although acknowledging that many different cognitive processes could lie behind slips of actions, a central theme in much of their work was that everyday mistakes resulting from absent

mindedness, such as pouring cream into a requested cup of black coffee, was a sustained attention (vigilant attention) problem (Robertson et al., 1997). However, this accreditation is not universal as others have ascribed the more general term lapses of attention rather than the more specific terms sustained attention or vigilant attention to these everyday mistakes leaving open the question of which attention operations they believe were responsible (Carriere et al., 2008; Cheyne et al., 2006; Seli et al., 2012a; Smilek, Carriere, & Cheyne, 2010). This is sensible given that "pouring cream into a requested cup of black coffee" represents a significant shift in the construct of sustained attention/vigilant attention from that of maintaining alertness and response readiness to changing stimuli.

In summary, the literature defining sustained attention can be broadly separated into two camps based on scope. One camp posits that sustained attention is primarily a state of vigilance for a yet to be presented stimulus. The other camp posits that sustained attention extends beyond signal detection and includes response selection, implementation, and ongoing monitoring. This difference in scope has been reflected by variations to the construct and subsequent taxonomies of sustained attention, which no doubt is the reason why Robertson and O'Connell (2010) lamented "Attention research has long been plagued by terminological confusion" (p. 79).

2.3.2 *Sustained Attention Performance*

Although, the taxonomy of attention, in general and specifically that for sustained attention, is far from being consolidated, in some respects the results from a failure of sustained attention do not appear to be disputed by the literature. Sustaining attention, particularly to taxing cognitive tasks, often comes at a cost referred to as the 'vigilance decrement' or 'time on task effect' (Aue et al., 2009). This decrement in performance is due to perceptual desensitization, and response bias (cf. Helton et al., 2005; Warm, Dember, Murphy, & Dittmar, 1992), which can manifest as either errors of commission or omission. These response failures are believed to be due to transient disruptions of the cognitive systems that rely on the frontal executive system (Manly et al., 1999; Padilla et al., 2006; Weissman et al., 2006). More specifically, these types of lapses are considered to involve reduced activity in the right inferior frontal gyrus, right medial frontal gyrus, and the anterior cingulated cortex (Hedden & Gabrieli, 2006; Weissman et al., 2006).

Although breakdowns in attention were recognised early in our history (e.g., Jastrow, 1905) it was not until 1948 when Mackworth (1948) investigated an apparent decrement in vigilance by radar operators that attention lapses began to be extensively reported by the literature in both applied and clinical studies with respect to delayed response times (Anderson et al., 2010; Hall et al., 2008; Williams et al., 1962), detection failures (Helton, Head, & Russell, 2011; Helton et al., 2009b; Johnson et al., 2007; Makeig & Jung, 1996; Robertson et al., 1997), and response errors (Ansari, Grabner, Koschutnig, Reishofer, & Ebner, 2011; Cheyne, Carriere, Solman, & Smilek, 2011; Posada et al., 2012; Rosenberg, Noonan, DeGutis, & Esterman, 2013; Spinelli et al., 2011).

A review of the extant literature concerning sustained attention suggests that performance in sustained attention tasks is affected by a large number of factors including those which Ballard (1996) has described as task parameters, environment characteristics and individual subjective characteristics. Task parameters, which Parasuraman, Warm, and Dember (1987; discussed in greater detail later in the chapter) have said influence signal discrimination type, event rate, modality and source complexity, have all been investigated in attention studies and found to impact performance during sustained attention tasks (Curtindale, Laurie-Rose, Bennett-Murphy, & Hull, 2007; Galinsky, Rosa, Warm, & Dember, 1993; Head & Helton, 2012; McCarthy, Beaumont, Thompson, & Peacock, 2005; Seli et al., 2012a; Seli, Cheyne, & Smilek, 2012b; Shalev et al., 2011; Taylor-Cooke & Fastenau, 2004). Task engagement has also been investigated in association with sustained attention. A study by Matthews, Warm, Reinerman, Langheim, and Saxby (2010) linked task engagement to sustained attention through the interactions of mood, performance motivations, concentration and arousal (see also Matthews & Davies, 1998). As Oken et al. (2006, p. 1888) point out in their review of the role of motivation in sustained attention "Performing a task with a high financial reward for performance will engage the attentional system stronger and with longer duration than performing the same task with no overt reward for performance." In fact, Langner's and Eickhoff's (2012) starting point was that those tasks, which we refer to as sustained attention tasks, were by definition monotonous tasks. Lastly, but by no means exhaustively, Atchley and Chan (2011) claimed that increasing arousal through the strategic placement of a secondary task could lead to an improvement in sustained attention.

There is also a comprehensive library concerning the impact of environmental factors on sustained attention ranging from stimulant use, noise, through to familial and socioeconomic factors (Colquhoun & Edwards, 1975; Lane & Phillips-Bute, 1998; Levine et al., 2006; Razza, Martin, & Brooks-Gunn, 2010). However, it is the category of 'individual subjective characteristics' that has been most comprehensively covered by the literature, and that seems almost exclusively to support the general premise echoed by Matthews and Davies (2001) and Washburn, Taglialatela, Rice, and Smith (2004) that sustained attention capability differs between individuals.

The reported reasons for this inter-individual variability are manyfold. For example, sustained attention has reportedly been influenced by the following subjective factors: age, gender, personality traits, mood, intelligence and executive control (Avisar & Shalev, 2011; Burton et al., 2010; Matthews & Davies, 2001; McAvinue et al., 2012; Ruocco & Direkoglu, 2013; Unsworth, Redick, Lakey, & Young, 2010), and working memory (Ahmed & de Fockert, 2012; Buehner et al., 2006; Carriere et al., 2008; Karatekin, Marcus, & Couperus, 2007). Furthermore, it should not be surprising that variability in sustained attention has also been linked to fatigue, circadian rhythms and homeostasis (Gritton, Kantorowski, Sarter, & Lee, 2012; Gunzelmann, Gross, Gluck, & Dinges, 2009; Gunzelmann, Moore, Gluck, Van Dongen, & Dinges, 2011; Larue, Rakotonirainy, & Pettitt, 2010).

Valdez, Ramírez, García, Talamantes, and Cortez (2010) reflected the overarching theme of those studies when they noted that as tiredness increases, three measures of sustained attention – short-term stability, general stability, and time on task stability – all decreased. They also found that circadian variation impacts both short-term and general stability but not time on task, though time on task is impacted by homeostatic variation.

2.3.3 *Theories of Sustained Attention*

A number of theories have been put forward to explain the variability in vigilance performance. Although now challenged (Matthews et al., 2002a), the traditional position has been that vigilance tasks are tedious and benign assignments that place little demand on monitors (Grier et al., 2003; Matthews & Davies, 1998). This is reflected by one of the first theories to account for these insidious lapses: the arousal theory. This theory is based on the premise that information processing is positively bound to motivation (Eysenck, 1982; Larue et al., 2010). In other words, the decrement in vigilance performance is due to a lack of exogenous stimulation needed to maintain alertness at an optimal level (Ballard, 1996; Eysenck, 1982). The theory proposes that repetitive stimulation leads to habituation which in turn reduces arousal and, as a consequence, there is a decline in performance (Smit, Eling, & Coenen, 2004b). In unusual surroundings there is utility in being alert and vigilant to danger. Unsurprisingly then, neurophysiological studies have demonstrated that links exist between the infralimbic cortex, the central nucleus of the amygdala, and the bed nucleus of the stria terminalis (neural sites associated with fear and emotion) with the locus coeruleus and tuberomammillary nucleus – sites associated with arousal (Cano, Mochizuki, & Saper, 2008). Conversely, there is also a utility in habituating to such stressors. However, this habituation can result in lowered motivation levels that, according to the arousal theory of sustained attention, are thought to reduce our ability to remain focused on the task at hand.

Another arousal-related theory, the mindlessness theory based on the work of Robertson and collaborators (Manly et al., 1999; Robertson et al., 1997) is similar. It was mentioned early in this chapter that they were influential in introducing the construct of mindlessness to sustained attention. They reported that everyday slips correlated positively with the results of the SART, a measure that they claim is a reliable marker of sustained attention and of action slips or absentmindedness (Manly et al., 1999; Robertson et al., 1997). Although not explicitly stated by them, the inference made was that the mindlessness responsible for everyday slips of attention is implicit in the etiology of lapses of sustained attention. This assumed cause and effect is often referred to as the 'mindlessness theory' (Grier et al., 2003; Head & Helton, 2012; Helton & Russell, 2011). It posits that sustained attention lapses are due to a mindless withdrawal of endogenous attentional effort during vigilance tasks (Helton et al., 2005). According to this theory, endogenous attention to critical signals has to be willfully maintained during the inter-stimulus interval where there is an absence of relevant exogenous stimulation. Therefore, in sustained attention tasks, where the interval between critical signals can be long, the assignment becomes at risk of being treated in a thoughtless, automatic manner. In this state the monitor's awareness becomes disengaged from the task allowing

attention to be captured by other more salient but irrelevant task unrelated thoughts (TUTs) that are not associated with the current task.

This theory aligns with the earlier work of Norman and Shallice (1986) and Stuss et al. (1995). These two influential papers postulated that basic cognitive operations are carried out in units or modules that are managed by automatic processes called schemata. These schemata are similar to what Schneider and Shiffrin (1977) have described as memory nodes that, according to Stuss et al., are triggered by perception or other schemata and are mediated by a supervisory system. Depending on the circumstances (i.e., whether the required solution is novel, or the schemata have only been weakly activated, or when specific schemata have to be activated, or when inappropriate schemata have to be inhibited) the supervisory system will respond by: energizing schemata, inhibiting schemata, adjusting contention-scheduling, monitoring the level of activity in schemata, or by controlling if/then logical decisions.

According to this model, if the sustained attention task only involves well-learned processes (i.e., press button in response to a sudden onset stimulus), it will be automatically managed by a set of schema. These schema, though, are at risk of becoming deactivated in between rare events unless their activation is monitored and maintained by the supervisory system (for a detailed description see Stuss et al., 1995).

The mindlessness theory has found support in a number of arenas. For example, reaction times immediately prior to errors of omission in the SART were quicker, indicating attention failures were preceded by periods of routinization (Dockree et al., 2005; Dockree et al., 2004). Neuroimaging studies have also revealed that several areas associated with the default mode network become more active in the period immediately prior to an attention lapse, a feature thought to reflect mind wandering (Bonnelle et al., 2011; Esterman et al., 2012; Hasenkamp, Wilson-Mendenhall, Duncan, & Barsalou, 2012; Meier et al., 2012). In another study, neutral cues were used to remind participants of the task goal with a resultant improvement in sustained attention compared to those who were not reminded (Manly et al., 2004). Separately, other neuropsychological and neuroimaging studies have established that top-down alerting systems and bottom-up arousal systems can be modulated by task demands, and may be responsible for switching between willful endogenous control of attention and an increased reliance on exogenous support and vice versa (O'Connor et al., 2011; Robertson & Garavan, 2004).

There have also been a number of behavioural studies that have aligned with Robertson's theory. For example, Manly et al. (1999) replicated Robertson et al.'s (1997) finding and also found a significant effect between the SART and the CFQ. Ruocco and Direkoglu (2013) deconstructed the trait 'mindfulness' into two components, present moment awareness, and acceptance, and found that higher reaction times were associated with decreased present moment awareness.

Cheyne et al. (2006), were concerned about the ecological validity of the CFQ in attention studies and devised what they termed the Attention-Related Cognitive Errors Scale (ARCES). This scale, which comprised of items from the CFQ, plus other items from Reason (1984) and the authors' own experience

that they considered to be relevant to attention, was found to correlate with the Mindful Awareness of Attention Scale (r = -0.54). In a later paper, Cheyne et al. (2009) credited task disengagement during sustained attention assignments to mindlessness and Smilek et al. (2010), and Carriere et al. (2008) were able to demonstrate a co-relationship between subjective boredom and performance on the SART. Forster and Lavie (2009) demonstrated a negative link between mindless TUTs and perceptual load (as perceptual load decreased TUTs increased), a result that has implications for the premise that low exogenous stimulation precipitates mindlessness. This is a result that converges with a review of sustained attention by Langner and Eickhoff (2012) who reported that it is usually harder to maintain attention in intellectually unchallenging, monotonous situations than in cognitively demanding but interesting ones. Lastly, Atchley and Chan (2011) demonstrated that reaction times can be improved by increasing arousal during monotonous vigilance tasks which is not inconsistent with the premise that low arousal leads to the vigilance decrement (see also Larue et al., 2010).

However, support for the mindlessness theory is not universal with a number of construct difficulties being reported. Prominent among these is the presumption that vigilance is not a demanding cognitive task. Warm, Dember, and Hancock (1996) were some of the first to question the view that vigilance is an under-arousing assignment. Using the NASA-task Load Index (TLX) (Hart & Staveland, 1988), Warm and colleagues found that the vigilance decrement was accompanied by a linear increase in overall workload, which they ascribed to an increasing demand in the psychophysical requirements of separating signals from noise. Grier et al. (2003) also disputed the notion that vigilance tasks are a mindless lack of attentional focus and similarly proposed that vigilance tasks impose a substantial mental burden. Using a vigilance task that simulated a quality control paradigm where the participants were to visually detect rare critical signals with a probability of .05 per period, they measured perceived mental workload, also using the TLX, and task-induced stress with the Dundee Stress State Questionnaire (Matthews et al., 2002a) and found that those participants assigned to the vigilance task were more worried post-vigil, were less engaged in the task, and more distressed than controls not engaged in vigilance. These results converge with those from Smit et al. (2004b) who similarly concluded that the vigil in sustained attention tasks is cognitively demanding. Moreover, Matthews and Davies (1998) noted that the vigil scored higher on the TLX than did memory searches, choice reaction time tasks, mental arithmetic, time estimation, simple tracking and grammatical reasoning.

Moreover, there is some debate as to whether mindlessness is the result of executive control failures. Mind wandering was defined by McVay and Kane (2010, p. 188) as “off task thoughts during an ongoing task or activity” and by Smallwood, Riby, Heim, and Davies (2006, p. 946) as, “a shift of attention from a primary task toward internal information, such as memories”. This class of repetitive thought has been considered to result from an executive control failure (McVay & Kane, 2009, 2010; Watkins, 2008). However, this proposition is not universally accepted. The Smallwood-Schooler theory of executive control theorizes that,

contrary to an executive control failure, mind wandering requires executive resources (Smallwood et al., 2006).

Another problem with the mindlessness theory is that other studies have demonstrated that an increase in task demands led to a decrease in vigilance performance, which is inconsistent with the predictions of the mindlessness theory. For example, Helton and Russell (2011) manipulated the vigilance task by varying the difficulty of detecting the go/no go signal. In their study, they used a stimulus (feature present) that visually 'popped out' and could be accomplished through parallel processing – and a stimulus (feature absent) that required serial processing (Thornton & Gilden, 2007; Treisman & Gormican, 1988). According to Treisman and Gormican, a target is easier to detect in an array when it contains a distinguishing feature that is absent in the distracters. They hypothesized that this type of search was a parallel cognitive process. By way of contrast, when the target is distinguished by the absence of a feature found in the distracters they concluded the search was by a serial cognitive process, and hence, took longer. Accordingly, Helton and Russell proposed that the SART was a more demanding vigilance task than the PVT and that the feature absent search would be more cognitively demanding in both the conventional PVT and the SART. They argued that if the resource theory was correct there would be a greater vigilance decrement in the feature-absent SART than in the feature-present PVT paradigm while the opposite findings would provide support for the mindlessness theory. They found a greater vigilance decrement in the search that required serial processing in the SART paradigm, which is contrary to expectations based on the mindlessness theory.

In another study, Helton and Russell (2012) used content-free cues and task switching to compensate for the effects of task monotony and goal habituation, which the mindlessness theory predicts should reduce sustained attention errors. However, contrary to those predictions they found a decrement in performance consistent with the control group who were not exposed to the content free cues or who switched task.

Another challenge to the mindlessness theory is centered on the premise that the mind-state allowing uncontrolled TUTs is the result of boredom per se. It has been suggested that TUTs occur because the executive system is unable to maintain focus on the task at hand (McVay & Kane, 2009). Furthermore, as previously discussed, other studies have also shown that not only does under-arousal mediate a decline in sustained attention performance, so does over-arousal (Matthews & Davies, 1998). Finally, other evidence suggests that arousal affects overall performance rather than the course of performance decrement (Jewett, Dijk, Kronauer, & Dinges, 1999; Smit et al., 2004b).

However, some of the biggest challenges to the mindlessness theory were to the methodologies of some supporting studies. As pointed out by Helton and Russell (2011), measures of mindlessness and boredom used in many studies have relied on phenomenological constructs, which risk linking test results with the way things seem and not necessarily with the way things are. Moreover, the CFQ used by Robertson et al. (1997) was written as a measure of self-reported failures in perception, memory, and motor function (Broadbent et al., 1982) and, as noted by Cheyne et al. (2006, p. 580), "The CFQ would seem to assess a

good deal more than attention-related cognitive failures." Another study, by Helton et al. (2005) also challenged the mindlessness of Robertson's et al.'s theory noting that the subtle temporal patterns used by monitors to predict the appearance of critical signals was a differentiating factor in both tasks that required a response to a critical signal or tasks that required a response to be withheld to a critical signal. They found that the temporal patterns benefited performance in the conventional vigilance paradigm where a response is required, but hindered performance in tasks where a response must be withheld, a task designed to promote a mindless withdrawal of attentional effort through routinization. Furthermore, response inhibition tasks such as the SART have been criticised for measuring executive functioning, not necessarily sustained attention (Ballard, 2001; Chan, Shum, Toulopoulou, & Chen, 2008; Ishigami & Klein, 2009), a conclusion supported by Helton et al. (2009b) and by Helton, Weil, Middlemiss, and Sawers (2010) who suggested that the SART is a better measure of response selection and impulsiveness than of sustained attention. Lastly, it has been pointed out that the routinization generated by the frequent presentation of non-critical signals in the SART could unduly promote a state of mindlessness thus biasing the results (Helton et al., 2005).

Despite these criticisms, the mindlessness theory continues to enjoy strong support. However, those studies that support the theory have tended to conceptualize sustained attention as being more than just a watch and wait assignment. They have adopted the expansive definition of sustained attention to include response selection and monitoring. Although the evidence and arguments correlating mind wandering, boredom and monotony to this extended construct of sustained attention are sometimes compelling (e.g. Cheyne et al., 2009), the studies have not demonstrated cause and effect. This leaves open the possibility that mindlessness may be symptomatic of sustained attention failures and not the cause of it.

Another theory belonging to what Helton and Russell (2012) have labeled the under-load theories, is the goal habituation theory proposed by Ariga and Lleras (2011). This theory postulates that maintaining an accurate goal representation is essential for successful performance during a wide variety of cognitive tasks including sustained attention. This responsibility falls to the executive system. However, the executive system can experience difficulty in maintaining the goal over a prolonged period of time. The theory resembles that of the mindlessness theory in so much as both accounts propose that the vigilance decrement is the result of awareness disengaging from the task because of under-load. However, it has failed to gain much attention from the literature because of methodological difficulties (for a review see Helton & Russell, 2012).

Resource depletion theory

The last of recent sustained attention theories reviewed in this chapter is the resource depletion theory. This theory postulates that the cognitive resources required for sustaining attention are limited. Over time and when demand is high cognitive resources become depleted (Helton & Warm, 2008; Langner & Eickhoff, 2012). Sustained attention tasks are far from the passive events they were once thought to be (Grier et al.,

2003; Matthews & Davies, 1998; Smit et al., 2004b). During a vigil, monitors need to make active, continuous discriminations between signal and noise under conditions of great uncertainty. At times, the demands placed on the resources needed for this mental task may exceed availability – a situation that according to the resource depletion theory leads to a performance decrement.

The resource depletion model is similar to the resource theory of sustained performance. According to Langner and Eickhoff (2012), the stabilization or reactivation of transient cognitive processes such as attention are required to maintain task engagement over prolonged periods of time. This stabilization or reactivation processes is effortful and depletes resources. As a consequence, when fatigued, the implementation of task-specific cognitive processes cannot be maintained at optimal levels, and performance declines.

An early resource-based theory was the capacity theory of attention proposed by Kahneman (1973). Kahneman's general principle was that our capacity to perform mental work such as attention is limited. According to this theory, mental effort is controlled by the demands of the task and not intent. Moreover, the vigilance taxonomy of Parasuraman et al. (1987), mentioned earlier in this chapter, aligns with resource-based theories of vigilance. They proposed that the form of signal discrimination – simultaneous or successive – and the event rate were important determinants of resource consumption. They say that if the signal is of the successive presentation form and is combined with a high event rate, working memory will be loaded and result in perceptual difficulties. They supported these findings by reference to inter-task correlations, which were reported to be constantly high (r = 0.6 – 0.8), but only when the stimuli were matched by presentation (i.e., simultaneous or successive). They also reported that vigilance sensitivity only changed during high presentation rates. These reports all align with the resource theory which was further championed by Warm and Dember (1998). They reviewed the literature surrounding Parasuraman and Davies' resource theory taxonomy. They concluded that not only was the taxonomy helpful in elucidating the impact of task differences on attention and in unravelling the hitherto mysteries of the vigilance decrement and workload imposed by vigilance tasks. It was also instrumental in "…a revolutionary new view of vigilance as an exacting, capacity-draining assignment that is associated with a high degree of mental demand and frustration" (p. 105).

Subsequently, a number of studies have supported the resource depletion theory (Grier et al., 2003; Head & Helton, 2012; Helton, Hayrynen, & Schaeffer, 2009a; Helton & Russell, 2011; MacLean et al., 2010; Matthews & Davies, 1998; Matthews et al., 2010). Among them is a study by Smit et al. (2004b) who added an irrelevant stimulus to a low demanding task. Smit et al. suggested this would increase arousal and according to the mindlessness theory, ought to improve performance because of the increase in arousal it would stimulate, but which according to the resource depletion theory would have no impact on sustained attention performance. They found that performance was unaffected by the added stimuli. They then tested whether a high-demanding task with the same additional irrelevant stimuli would cause a greater decline in performance compared to the low demand; as indeed it did. This led them to conclude that vigilance

decreased because of resource depletion due to mental workload. MacLean and collaborators (2010) trained participants in signal discrimination using meditation techniques. They found this increased perceptual sensitivity and, therefore, reduced the demand on resources making it easier to sustain attention. However, it has been shown in other studies that observers with the most acute vision or hearing do not always make the best monitors (Finomore, Matthews, Shaw, & Warm, 2009). Helton and Warm (2008) used two levels of signal saliency and found that changes in saliency levels and thus presumably workload, had a corresponding effect on the vigilance decrement; a conclusion supporting the resource theory. Matthew, Davis and Roy (1998) reported on a number of studies into arousal, task demands and vigilance using both single and dual tasks. They concluded that vigilance performance is resource related. In particular they noted that individuals with high levels of energetic arousal performed better on vigilance tasks where the task demand was high.

However, Ungar (2009) had mixed results. He examined transition effects from a high to a low demanding task on performance by altering signal saliency and by transitioning between a single task and a dual task. Although he found that the results favoured the resource depletion theory when the task was difficult, the results also favoured the mindlessness theory when the task was easy.

In general, the literature on sustained attention appears to have mostly accepted the resource theory of sustained attention, which is probably why Helton and Russell (2012, p. 37) felt confident enough to proclaim "The dominant theory amongst vigilance researchers is resource theory." However, it is not entirely without its critics. Amongst those were Ariga and Lleras (2011) who drew their reader's attention to the absence of commentary on what resources were being depleted.

Yet that commentary is not entirely absent. Finomore et al. (2009) pointed to a "limited-capacity pool of energy reserves" (p.793), albeit they did not explain what was exactly meant by 'energy reserves'. It could also be inferred from Matthews et al. (1998) that energetic arousal was considered a resource when they said, "high energetic arousal individuals have more resources available" (p.132). Langner and Eickhoff (2012) suggested that self-regulation – an important correlate of mindlessness – was a limited resource, as did Fennis and Janssen (2010), and Langer (2012) pointed more broadly at cognitive processes without being specific as to what process are limited. Recently near-infra red spectroscopy (NIRS) was used to measure brain blood oxygenation levels during a sustained vigilance task (De Joux, Russell, & Helton, 2013). Their results showed that the right hemispheric oxygenation levels were elevated compared to those in the left hemisphere and that there was an average bilateral increase in oxygenation with time on task, indicating an increased utilisation of cerebral resources occurs over time (Pfurtscheller, Bauernfeind, Wriessnegger, & Neuper, 2010). In part, these results replicate earlier studies by Helton et al. (2007), who used transcranial Doppler sonography (TCD) and transcranial cerebral oximetry to measure brain hemodynamics during an abbreviated vigilance task, and Warm, Matthews, and Parasuraman (2009), who reported on five other studies that had used TCD and NIRS.

These results are not surprising given the right lateral hemisphere's association with sustained attention (Bonnelle et al., 2011; Lawrence, Ross, Hoffmann, Garavan, & Stein, 2003; Poudel, 2010). But given that other networks have also been implicated in sustained attention, (Hilti et al., 2013; Lawrence et al., 2003; Posner & Petersen, 1990), much has yet to be elucidated concerning precisely what resources are being depleted. This later point was also made by Matthews et al. (2010) who acknowledged that while task-evoked individual differences in resource availability may be able to be indexed by blood flow, localizing the neural systems and developing a resource model that integrates the physiological and subjective concomitants of resource availability would be challenging. Thus, while there are studies that have commented on possible resources behind the resource theory, there is not a general convergence of opinion and as pointed out by Ratcliff and Van Dongen (2011), the components underlying sustained attention responses still need to be determined.

Other critics of the resource depletion theory, and incidentally of the mindlessness theory as well, are (Langner & Eickhoff, 2012; Langner, Willmes, Chatterjee, Eickhoff, & Sturm, 2010). Although Langner and colleagues conceded that while there was ample evidence in support of both the depleted resources theory and the mindlessness theory, neither theory was by itself sufficient to fully explain all the available data. They stated that while resource depletion was a necessary condition for sustained attention failures, sustained attention was more than, "a continuous form of focused, goal-directed attention, being controlled in a purely top-down manner" (Langner & Eickhoff, 2012, p. 17). They suggested a self-regulatory model of sustained attention that synthesized both the mindlessness theory and the resource depletion theory. In their model, they suggest that during vigilance tasks, over time, an imbalance could occur between the subjective costs (i.e., effort and exertion) and the benefits (i.e., intrinsic rewards). If left unresolved, this imbalance would eventually result in absentmindedness and mindlessness unless countered by the deployment of self-regulatory control – a construct similar to Stuss et al. (1995) supervisory-system used to mediate schemata. However, during intellectually simple, monotonous tasks this self-regulatory control, which Hagger, Wood, Stiff, and Chatzisarantis (2010) state is a limited resource, becomes depleted (Langner & Eickhoff, 2012) Conversely, during attentionally demanding but intrinsically rewarding tasks, where the cost benefit equation is assumed to be more in-balance, 'self-regulatory-power' is not depleted to the same extent. Langner et al., say this account, which they caution has yet to be directly support by empirical evidence, could provide a possible explanation for the specific difficulty of sustaining attention on monotonous tasks.

2.4 Arousal

Cortical arousal is the second of the two systems implicated in lapses of responsiveness. It is an important construct in the study of lapses because of its direct involvement in microsleeps and its indirect involvement in attention lapses. According to Poudel (2010), fMRI studies have shown that not all lapses of

responsiveness stem from executive dysfunction (see Chee et al., 2008). Poudel et al. (in press) found evidence of activity in the arousal system and visual processing areas during a lapse of responsiveness additional to transient failures of the frontal executive systems following sleep deprivation (see also Groeger & Brown, 1989). Chee et al. (2008), reported important differences in cortical activation between sleep-deprived and rested participants experiencing lapses of a similar duration that pointed to cortical regions other than the frontoparietal being implicated in lapsing. These differences were particularly apparent in the attenuation of extrastriate activation, which they concluded may proceed a more widespread shutting down. They also found lapses were related to slower thalamic activation in sleep-deprived participants than in rested participants. Moreover, they found that task-related thalamic activity was higher in sleep-deprived than in rested participants. Like attention lapses, arousal-related lapses of responsiveness can manifest as response errors, delayed responses (Doran, Van Dongen, & Dinges, 2001), detection failures (Davies & Parasuraman, 1982; Mackworth, 1948), and in microsleeps (Peiris et al., 2006b).

Arousal is another construct whose taxonomy has been deplored for its looseness (Andrew, 1974). According to the Penguin Dictionary of Psychology (2010) its use has become so general that it should only be used with a qualifier, i.e., 'cortical' arousal. Nonetheless we use the term unqualified in this thesis but meaning cortical arousal. Penguin defined arousal as a heightened state of cortical functioning involving sensory excitability, glandular and hormonal levels and muscular readiness (Reber, 1995). Others have said it is being aware of the world, the counterpart of which is sleep (Campbell, Reece, & Mitchell, 1999). Generally though, it is taken to mean the physiological and psychological state of being aware through involvement of the activating reticular system (Saper, Scammell, & Lu, 2005), the autonomic nervous system (Kreibig, 2010), and the endocrine system (Quick, Quick, Nelson, & Hurrell, 1997). It is a continuum where high levels of excitability and wakefulness exist at one end while the other end represents sleep through to anaesthesia and to coma.

Arousal is conceptualized to consist of two mood states, tense and energetic (Thayer, 1987, 1989, 2012). Tense arousal represents a continuum from calmness to anxiety, whereas energetic arousal reflects a continuum from tiredness to energetic, which is what Dickman (2002) has described as the separate dimensions of vigor and wakefulness. Thayer conceptualized energetic arousal as a 'go system'. When energetic levels are high the person is motivated to act, and to do something. When it is low then the tendency is for rest and recuperation. On the other hand, tense arousal is conceptualized by Thayer to be a 'stop system' that when high predisposes a person to caution, waiting and stopping (Thayer, 2012).

2.4.1 *The Role of Arousal in Sustained Attention*

According to Matthews et al. (2010), an association between attention and arousal is neither new nor controversial. Although considered to be distinct from and conceptually different from sustained attention (Oken et al., 2006), arousal through its association with the sleep/wake cycle was demonstrated by Mackworth (1950) to overlap with attention when he reported that the administration of the stimulant drug

amphetamine reduced the vigilance decrement (see also Chee et al., 2008; Matthews & Davies, 1998). Moreover, one of the first theories put forward to explain the vigilance decrement was the arousal theory proposed by Eysenck (1982). Even earlier Lynn (1966) had observed that attention and arousal were related through their mutual dependency and complimentary expression. Matthews (1990) reported a cause and effect of arousal on sustained attention. He manipulated the type of discrimination (successive or simultaneous), type of task, and signal discriminability during a sustained attention task and found that high self-reported levels of arousal were correlated with higher performance; a finding that led Matthews to conclude that arousal increases the availability of resources for sustained attention.

According to Matthews et al. (2010), the link between arousal and attention is the general performance theory of Humphreys and Revelle (1984), which when considered alongside Thayer's energetic arousal construct that Matthews et al. (2002b) proposed was an index for cortical arousal, suggests that energetic arousal increases the availability of sustained information transfer resources that are necessary for attention (Matthews et al., 2002b). This has been demonstrated by behavioural studies that have found a positive association between individual levels of energetic arousal and sustained attention (Matthews & Davies, 2001; Matthews et al., 1990). In a separate study, energetic arousal and tense arousal were measured during a traditional response format vigilance task and a SART (Stevenson, Russell, & Helton, 2011). Using the Dundee Stress State Questionnaire (Matthews et al., 2002b), they showed that energetic arousal levels declined during the tasks while tense arousal levels increased relative to pre-task baseline levels .

Additional to those studies, there is also neuropsychological evidence of a causal relationship between arousal and attention. For example, Oken et al. (2006) pointed out that the locus coeruleus norepinephrine system, which is considered important for sleep–wake state changes, also becomes phasically active during attention to environmental stimuli in the awake state (See also Howells, Stein, & Russell, 2012). In an fMRI study to measure brain activity during the performance of an attention task under different levels of arousal, Portas et al. (1998) found that activity evoked in the ventrolateral thalamus by the attention tasks changed as a function of arousal with higher activity when arousal levels were lower (see also Chee & Chuah, 2008). This finding converges with the work of Coull (1998) who concluded that the thalamus acts as a compensatory mechanism when attention is used under a state of low arousal. It also converges with Saper, Fuller, Pedersen, Lu, and Scammell (2010) who proposed that γ-aminobutyric acid (GABA)ergic neurons in the thalamus sample thalamocortical traffic and, by this means, the thalamus is able to focus attention by inhibiting thalamic relay neurons. In addition, sleep deprivation has been found to decrease activation of the medial prefrontal cortex during sustained attention tasks (Chee & Choo, 2004). The medial prefrontal cortex, which is a major cortical source of inputs to the wake-sleep system, also plays a critical role in selective attention (Saper et al., 2010).

Arousal has also been implicated in sustained attention failures, including delayed responses (Dinges & Kribbs, 1991), response errors (Zhang et al., 2012), and detection failures (Singh, Molloy, & Parasuraman, 1993; Wilkinson, Morlock, & Williams, 1966). These studies all point to an optimal level of arousal for

maximal sustained attention performance, that, despite being an oversimplification, can be summarised by the Yerkes Dodson curve (Matthews et al., 2010), which shows that too little arousal results in poorly sustained attention, as does too much.

Sleep is almost synonymous with decreased arousal. This is not surprising given that arousal and sleep represent the two poles of the sleep/wake continuum. Poudel et al. (2010; in press) suggest that microsleeps are in fact the result of disruptions to the arousal system; a proposition supported by other studies (Bakotic & Radosevic-Vidacek, 2012). For example, Dementienko et al. (2008) in one instance discusses operator error as the result of increased drowsiness accompanied by microsleeps and in another instance as the result of decreased arousal. Gould et al. (2009) in their study into the effects of sleep deprivation on new labour saving technology went further and ascribed the cause of microsleeps to lowered arousal, as did Corfitsen (1999). However, given the close link between arousal and microsleeps and in particular low arousal and sleeping, further discussion on arousal and microsleeping is reserved for later sections in this chapter. In between, we review the literature concerning the neurophysiology of arousal and sleep.

2.4.2 *The Neurophysiology of Arousal*

Arousal implicates several discrete neuronal populations that comprise the ascending reticular activating network. This network operates a dorsal pathway through the thalamus that activates the thalamic relay neurons, crucial for gating information to the cerebral cortex, and a ventral pathway that bypasses the thalamus but activates neurons in the lateral hypothalamus, the basal forebrain, and the cerebral cortex (Saper et al., 2005; Schwartz & Roth, 2008). The dorsal pathway consists mainly of cholinergic afferents from the pedunculopontine tegmental and the laterodorsal tegmental nuclei that project to the thalamic-relay nucleus and to the thalamic-reticular nucleus, a structure thought to be implicated in shaping slow wave activity in NRMS (Connelly & Errington, 2012) and in alertness (Sturm et al., 1999). The ventral pathway consists mostly of monoaminergic cell populations, including the noradrenergic locus coeruleus, the serotoninergic dorsal and median raphe nuclei, the dopaminergic ventral periaqueductal grey matter, and the histaminergic tuberomammillary neurons. Furthermore, this input to the cerebral cortex is augmented by lateral hypothalamic peptidergic neurons containing either melanin-concentrating hormone or orexin/hypocretin (subsequently referred to as orexin), and basal forebrain neurons containing acetylcholine and GABA (Hassani, Lee, & Jones, 2009; Saper et al., 2005; Schwartz & Roth, 2008). In turn, the orexin neurons receive inputs from the infralimbic cortex, and the SCN via the dorsomedial nucleus of the hypothalamus (Hara & Sakurai, 2011; Saper et al., 2010). All these neurons act in a coordinated manner, albeit with significant overlap, to produce arousal. Disruption to these networks has been demonstrated to result in sleep (Saper et al., 2005). For example, people with narcolepsy often present with very low or undetectable orexin levels in the cerebrospinal fluid. Narcolepsy is a sleep disorder characterised by excessive daytime sleepiness and sudden outbreaks of rapid eye movement sleep (REMS) (Hara & Sakurai, 2011). Moreover, damage to the rostral hypothalamus, an area that includes the ventrolateral preoptic area

(VLPO) and the median preoptic nucleus (MnPN), causes chronic sleep loss (Szymusiak, Gvilia, & McGinty, 2007).

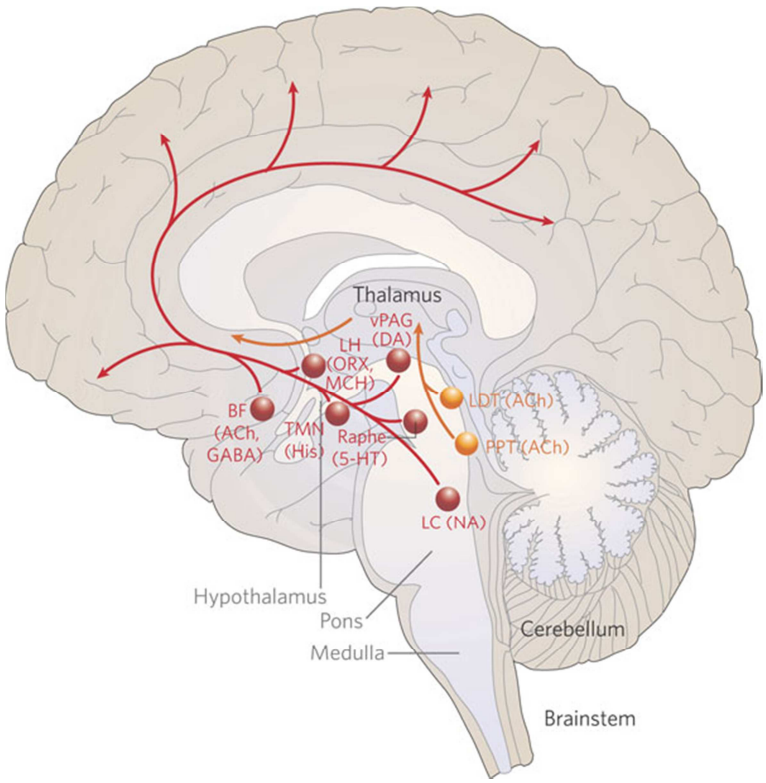

Figure 2-1 A schematic drawing showing the main components of the two pathways that constitute the ascending reticular network considered to be responsible for arousal. The ventral cholinergic pathway is represented in orange and the dorsal mainly monoaminergic pathway is shown in red. Ach, Acetylcholine; BF, basal forebrain; DA, dopamine; GABA, gama- aminobutyric acid; His, Histamine; LC, Locus coeruleus; LDT, laterodorsal tegmental nucle; LH, lateral hypothalamus; MCH, melanin-concentrating hormone; NA, noradrenaline; ORX, orexin; PPT, pendunculopontine; raphe, dorsal and median raphe nuclei; TMN, tuberomammillary nucleus; vPAG, ventral periaqueductal gray matter; 5-HT, serotonin. (Saper et al., 2005).

2.4.3 ***Drowsiness***

Drowsiness is a construct that is synonymous with sleepiness (Johnson et al., 2011). Unfortunately, like the other constructs discussed, at first glance it appears to have been variously described, often loosely. This is probably due to it being a complex interaction of behavioural (Wierwille & Ellsworth, 1994), physiological (Putilov & Donskaya, 2013), and emotional constructs (Claghorn, Mathew, Weinman, & Hruska, 1981), of which some (particularly the latter) can be notoriously difficult to define (Lang, 2010). As a consequence, it is worthwhile reviewing the literature on drowsiness because of its relevance to the construct of microsleeps.

Wierwille and Ellsworth (1994) used overt behavioural features to identify stages of drowsiness. For example, they proposed that people who were not drowsy would display normal eye movements and normal facial tones. As people progressively become drowsy their driving performance will decline and they may start to rub their eye or face, perhaps scratch themselves and move restlessly in their seats. It is also possible their facial tone may decrease, and they may appear glassy-eyed. When very drowsy, they may close their eyes for periods between 2 to 3 s or longer, accompanied by a rolling upward or a sideways movement of the eyes themselves. They may also appear not to be focusing the eyes properly, or may exhibit a cross-eyed lack of proper vergence. They may also show some incoherency in any task they are doing. Finally, people who are extremely drowsy and falling asleep will usually exhibit prolonged eyelid closures (4 s or more) with similarly prolonged periods of inactivity. There may be large punctuated movements as they transition in and out of intervals of dozing (1994). In the same vein, Flores, Armingol, and de la Escalera (2010) used yawn frequency, eye-blink frequency, eye-gaze movement, head movement, and facial expression to measure drowsiness, which they consider is a measure of driving performance. Yet others (e.g., Alessi et al., 2000) have defined drowsiness as a function of activity. Finally, Borghini, Astolfi, Vecchiato, Mattia, and Babiloni (In press) likened drowsiness to a less stable form of mental fatigue. Mental fatigue, they say (p.4), "is a gradual and cumulative process and is thought to be associated with a disinclination for any effort, a general sensation of weariness, feelings of inhibition and impaired mental performance, reduced efficiency and alertness."

Slater (2008), defined drowsiness in terms of cortical processing efficiency. This resource-based proposal was founded in part on BOLD fMRI studies that revealed a pattern of increased cortical utilization corresponding to increased task complexity, both in a planning task and execution of a task. It was also based on a magnetic source imaging study that revealed a linear decrease in global cohesion as arousal increased. Fundamental to this proposition is that cognition can be conceptualised as the result of a layered process of increasingly complex neural networks. Increased drowsiness demands more complex neural networks to achieve the same result as when not drowsy, thus using greater mental resources.

The main difficulty with all of these definitions is that they are behaviouristic and describe drowsiness in terms of performance, which is insufficient to reveal the terms proper essence. In this respect, some of the better definitions are found in the following literature. For example, Sahayadhas, Sundaraj, and Murugappan (2013) defined drowsiness as synonymous with sleepiness, which they quantified by adding that the degree of drowsiness experienced would depend on: time of day, quality of the last sleep, current task, time awake, and amount of sleep deprivation; factors which Saper et al. (2010) recognised as circadian, homeostatic, and allostatic sleep drivers. Sahayadhas et al. (2013) suggested that this state reflects a propensity for sleep (see also Bakotic & Radosevic-Vidacek, 2012). Johnson et al. (2011) similarly defined drowsiness as belonging to an alertness/drowsiness continuum where drowsiness was the combined probability of sleep onset and distraction, as did Putilov and Donskaya (2013) who described it as a transitional state between wakefulness and sleep.

Attempts have been made to measure drowsiness through self-reported sleepiness scales, and EEG indices. Putilov and Donskaya (2013) concluded after a review of the literature that EEG and the Karolinska sleepiness scale (KSS) are both reasonably reliable measures of sleepiness, despite self-perceived measures of sleepiness not always reliably correlating with other objective measures. One of the most widely used self-reports, the (KSS) (Åkerstedt & Gillberg, 1990; Putilov & Donskaya, 2013) is a 9-point Likert scale validated against EEG correlates of sleepiness and, according to Åkerstedt and Gillberg, positively correlated with theta power. The mean sleep latency test (MSLT) is another often reported measure. However, as pointed out by Putilov and Donskaya, it may be more a measure of sleep ability, than sleepiness per se.

Conversely, EEG studies, are considered to give simple, efficient, reliable, and objective metrics capable of measuring sub-states along the sleep wake continuum (Putilov & Donskaya, 2013). Torsvall and Åkerstedt (1988) used EEG in a study into the effects of on-call duty on sleep and wakefulness. Åkerstedt and Gillberg (1990) later used EEG to validate the KSS. More recently, Putilov and Donskaya (2013) used EEG to devise a simplified drowsiness test called the Karalinska drowsiness test (KDT). In addition, and following a lead from Makeig and Inlow (1993), who demonstrated that vigilance performance was associated with the 2nd principal component of the EEG spectrum, and motivated by reports that self-rated sleepiness scales were positively correlated with theta power and negatively correlated with alpha power used those indices to construct a simple alertness scale that they say is the EEG equivalent of the KSS (Donskaya, Verevkin, & Putilov, 2012; Putilov & Donskaya, 2013).

The link between drowsiness and microsleeps was evident in Wierwille and Ellsworth's (1994) definition of very and extremely drowsy states that prescribed eye-closure and apparent lack of response. It was clearly evident in the study by Moller et al. (2006), which investigated microsleeps, as well as simulator performance and subjective sleepiness to assess drowsiness; and it was explicitly stated by Dementienko et al. who said "Most researchers believe that drowsiness accompanied by short (3- to 10-s) episodes of 'microsleep' is a direct cause of various traffic and industrial accidents" (2008, p. 592).

Despite significant etymological differences, this review indicates that the construct of drowsiness as a state is reasonably well consolidated. Significantly, the definitions reviewed generally converge and agree that drowsiness is not an invariant, but is instead a quantifiable variable, occupying a segment of the arousal continuum between the sleep and awake states. Furthermore, it can be measured by both self-reports of sleepiness and according to Putilov and Donskaya (2013) by using electrophysiological means.

2.5 Sleep

Sleep, the antonym of arousal, is a natural self-regulating state interspersed between episodes of wakefulness that for most sleepers recurs around the same time every day. It is characterized by a reduction in motor control, an increased arousal threshold, and a stereotypical EEG spectrum and posture (Fuller,

Gooley, & Saper, 2006). Setting aside conjecture (Slater, 2008), the reason why we sleep remains elusive (Daan, 2011; Hayaishi, 2011). However, the effects of not getting enough sleep are well documented, particularly with respect to sustained attention (for example Dinges et al., 1997; Gunzelmann et al., 2011; Horowitz, Cade, Wolfe, & Czeisler, 2003; Jung, Ronda, Czeisler, & Wright, 2011) and to a lesser extent microsleeps (Hemmeter, Bischof, Matzinger, Seifritz, & Hoslboer-Trachsler, 1998). Importantly, a clear understanding of sleep and the sleep processes are required if microsleeps are also to be understood.

2.5.1 *Sleep Structure*

During extended periods of consolidated sleep the sleep structure alternates between non-rapid eye-movement sleep (NREMS) and REMS. These two sleep states along with the wakefulness state are reflected by cortical EEG activity. During the awake period, differences in the timing of cognitive, perceptual and motor processes, result in the cortical EEG typically containing desynchronized beta waves, which are high-frequency, low amplitude waves in the 14–30 Hz range. However, when at rest with eyes closed but still awake, the EEG oscillations begin to synchronize and manifest predominantly as alpha waves in the 8–12 Hz range. During the NREMS state of humans, three stages are differentiated (subsequently referred to as N1, N2 and N3). A diminishing conscious awareness and a slowing EEG characterize N1 with oscillations typically in the 4–7 Hz theta range. By N2, consciousness has completely disappeared and the EEG shows evidence of sleep spindles and K-complexes. N3 is typified by the appearance in the EEG of delta waves (1–3 Hz), sometimes referred to as slow-wave activity.

REMS typically consists of high frequency, low amplitude, desynchronized EEG activity similar to that of N1 sleep and wakefulness in humans. However, in contrast to wakefulness and NREMS, REMS is accompanied by rapid eye movements and indications of profound muscular atonia. A typical night's sleep usually begins with a brief period of N1 followed by periods of N2, and N3 sleep before cycling back through N2 to enter a period of REMS.

In general, this ultradian cycle which is generated by the reciprocal interaction of aminergic and cholinergic brainstem structures (Dijk & von Schantz, 2005) lasts for approximately 90 min and, dependent on the length of sleep, is repeated between four to six times (Bixler & Vela-Bueno, 1987). As sleep progresses, the amount of time spent in REMS increases while the time spent in NREMS decreases. Overall, a typical adult would spend between 5–10% of consolidated sleep in stage 1, 50–60% in stage 2, 10–20% in stage 3, and between 20–25% in REMS (Dijk & von Schantz, 2005).

2.5.2 *Sleep Regulation*

Daily rhythms in sleep and wakefulness, are thought to arise from ancient activity/rest cycles where for pragmatic reasons, activity mostly occurred during daylight, and rest during the night time period (Porkka-Heiskanen & Strecker, 1997). This diurnal oscillation from wakefulness to sleep occurs when the arousal system is switched off through the influence of circadian and homeostatic sleep promoting processes

(Borbély, 1982; Fuller et al., 2006; Schwartz & Roth, 2008). How this could occur has been summarized by Borbély (1982) in his 'Two Process Model' of sleep regulation

One of the more prominent theories of sleep onset, Borbély's model proposes that circadian rhythms (what he called process C) interact with a homeostatic drive (process S) to regulate sleep. Borbély proposed that somnogens such as adenosine and serotonin accumulate throughout the wakeful period. However, their immediate effect on sleep propensity is offset by a wakeful physiology attuned to the circadian rhythm with the result being a consolidated period of wakefulness. However, after prolonged wakefulness the circadian sleep drive begins to wane and eventually the adenosine concentrations reach the point where they overcome the circadian wakefulness promoting state and can inhibit the neural activity in the wake-promoting circuitry of the basal forebrain and activate sleep-promoting VLPO neurons. During sleep, somnogen levels drop, where they in turn are overcome by a waxing circadian drive for wakefulness thus beginning a new cycle (Figure 2-2).

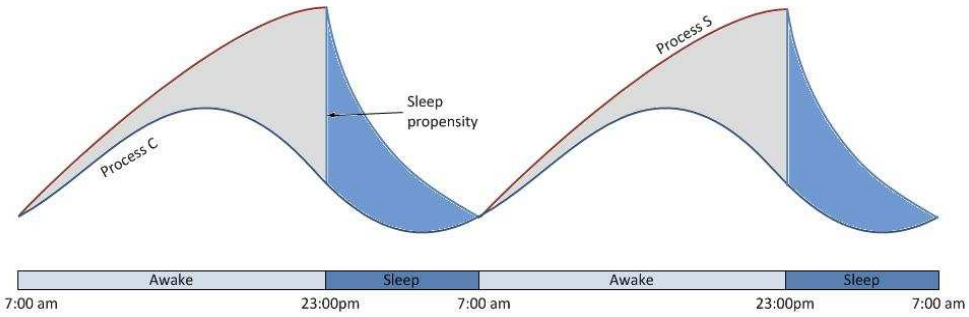

Figure 2-2 A schematic of Borbély's two process sleep model showing the time course of the homeostasis process S and the circadian process C. (Adapted from Borbély, 1982)

The circadian drive and the homeostatic drive, both considered to be oscillators by Dijk and von Schantz (2005), are in turn modulated by external oscillators – what Saper et al. (2010) have referred to as allostatic factors – and as internal oscillators by Dijk and von Schantz (2005). Examples of external oscillators include the light and dark circadian cycle, and social timings such as work rosters, mealtimes, and socially mediated bedtimes; while examples of internal oscillators include the accumulation and dissipation of neurochemicals such as adenosine, orexin, prostaglandin D_2, and serotonin (Gallopin et al., 2005; Hayaishi, 2011). In addition, synaptic weightings due to daytime neuronal activity that require night time re-correction (Dijk & von Schantz, 2005) and personality traits (Taub, Hawkins, & Van de Castle, 1978) are also internal oscillators.

As suggested by Borbély's Two Process model of sleep, the circadian rhythm and the homeostatic sleep drive, which in humans contribute approximately equal influences over the sleep/wake cycle (Dijk & von Schantz, 2005; Srinivasan et al., 2009), differ in their roles. The circadian oscillator is mostly responsible

for the regulation and maintenance of the normal sleep/wake cycle, whereas what Dijk and von Schantz have called the homeostatic oscillator is mostly responsible for determining the amount of sleep (Shiromani et al., 2004). Entrainment of the sleep-wake process occurs when these two oscillators are synchronized, which, according to Dijk and von Schantz (2005), is presumed to occur through the effects of photic cues on one or both of the two oscillators

2.5.3 *Circadian Drive for Sleep*

The circadian drive for sleep has a rhythmicity of approximately 24 hrs, regulated by the body's pacemaker, the suprachiasmatic nucleus [SCN], which itself is intrinsically rhythmic (Appleman, Figueiro, & Rea, 2013; Dijk & von Schantz, 2005; Fuller et al., 2006; Saper et al., 2010; Shiromani et al., 2004; Zee, Attarian, & Videnovic, 2013). The circadian drive reaches its maximum strength at the end of the biological night when the core body temperature is at its lowest. This nightly increasing drive helps to counteract the waning homeostatic influence, which is maximal at the beginning of sleep, thereby helping to consolidate sleep (Dijk & von Schantz, 2005).

The body's pacemaker is entrained to the light/dark cycle by photoperiodic information transmitted through the retinohypothalamic pathway/tract by photosensitive retinal ganglion cells that express the photopigment melanopsin (Saper et al., 2010). Driven by this rhythmicity, the SCN regulates the expression of clock genes that in turn regulate the expression of many other genes. For example, the accumulation of the neuro-somnogen adenosine because of cortical activity is regulated by the actions of two enzymes, adenosine kinase and adenosone deaminase that are maximally active during the night and minimally active during the daytime (de Sa´nchez et al., 1993).

However, the SCN does not project directly to the sleep/wake regulatory systems (Saper et al., 2010). Instead it projects extensively to the subparaventricular zone that in turn projects to the dorsomedial nucleus of the hypothalamus. This nucleus contains GABAergic neurons that heavily innervate and inhibit the sleep-promoting VLPO, and glutamatergic neurons that excitedly innervate the wake-promoting lateral hypothalamic area including orexin neurons (Chou et al., 2003; Saper et al., 2010; Srinivasan et al., 2009). By passing through the dorsomedial nucleus of the hypothalamus the SCN is able to influence the wake/sleep cycles, yet still allow other oscillators to make inputs into it (Saper et al., 2010).

Just as importantly for the regulation of sleep, the SCN is itself regulated through the melatonergic system and is therefore able to stop exciting wake promoting processes and disinhibit those promoting sleep (Srinivasan et al., 2009). Called the 'hormone of darkness' (Dijk & von Schantz, 2005) because it is produced almost exclusively at night, melatonin acts on the SCN through melatonin receptors MT1 and MT2 . This neuromodulation acutely inhibits neuronal firing in the SCN allowing the promotion of sleep.

The prostaglandin D_2 (PGD_2) system has also been implicated in the circadian sleep process (Gallopin et al., 2005; Hayaishi, 2011; Urade, 2011); with Urade (2011, p.10). going as far as to state, "Prostaglandin D2 is the most potent endogenous sleep-promoting substance thus far reported". Urade reported that PGD_2

concentration levels in the cerebral spinal fluid of rat brains waxed and waned in synchrony with the sleep wake cycle and mirrored sleep propensity even becoming elevated following sleep deprivation.

PGD_2 is a hormone biosynthesized by non-neuron cells, such as the leptomeninges, choroid plexus, and oligodendrocytes, and secreted into the cerebrospinal fluid where it circulates throughout the ventricular and subarachnoid spaces. It binds to PGD_2 receptors (DP1 receptors) localized in a small area of the leptomenges covering the ventral-rostal surface of the basal forebrain, thereby increasing extracellular concentrations of adenosine in a dose dependent manner (Hayaishi, 2011; Urade, 2011).

2.5.4 *The Homeostatic Sleep Drive*

The homeostatic sleep drive is the second of Borbély's two sleep regulating processes. The primary function of the homeostatic sleep system is to determine and set the amount of sleep. This function is driven by the sleep/wake cycle where prior time asleep and awake holds an influence on current sleep and wake propensity. In the words of Porkka-Heiskanen and Kalinchuk (2011, p. 124), "It is important to understand that neural activity during waking is a central regulator of subsequent sleep." Early mornings and late nights will generate a higher sleep propensity than will late mornings and early nights.

During the wake period, the somnogens adenosine and serotonin progressively accumulate (Gallopin et al., 2005) with adenosine reaching its maximum concentration at the end of the wakeful day. Adenosine is derived from intracellular neurone metabolism of ATP and extracellularly by astroglial cell metabolism (Frank, 2013; Porkka-Heiskanen & Kalinchuk, 2011). Neuronal and astrocyte activity requires energy that is obtained by the hydrolysis of adenosine triphosphate and an end product of that metabolism is adenosine. Consequently, adenosine accumulates in the extracellular space in the basal forebrain during prolonged periods of wakefulness (Porkka-Heiskanen & Kalinchuk, 2011). Conversely, during NREM sleep and in particular N3, energy metabolism decreases (Maquet, 1995) and the resultant biosynthesis of adenosine through neuronal activity declines.

Overlay this activity-driven production cycle of adenosine with the circadian activity of adenosine kinase and adenosine deaminase, the enzymes responsible for metabolising adenosine, and prostaglandin-mediated circadian increase/decrease in basal forebrain extracellular adenosine, and the result is a maximal accumulation of adenosine at the end of the day just prior to sleep onset and a maximal decline in adenosine concentration prior to the beginning of a further wake episode (Porkka-Heiskanen & Kalinchuk, 2011).

Serotonin, on the other hand, is synthesized in the terminals of widespread brain stem projections to limbic, cortical and subcortical structures where they regulate mood, appetite and aggression in addition to sleep (Frank, Stryker, & Tecott, 2002). More specifically, serotonergic neurons project from the dorsal raphe nucleus via the medial forebrain bundle, thence to the diencephalon, the basal ganglia and the basal forebrain from which they project widely to the cerebral cortex. In addition, there are serotonergic projections from the raphe nuclei to the cerebellum and into the spinal cord (Woolsey, Hanaway, & Gado, 2008). The dorsal and median raphe nuclei constitute part of the monoaminergic system that in turn is part

of the ascending reticular arousal system (Saper et al., 2010). However, along with adenosine, serotonin's role in the mediation of sleep is primarily through its influence on the ventrolateral preoptic nucleus (VLPO), an important structure in the sleep process. (Gallopin et al., 2005; Urade, 2011).

2.5.5 *The Sleep/wake Transition*

The transition between consolidated sleep and wakefulness depends on a stable switching mechanism that in one state suppresses the arousal system, and in another promotes it. The VLPO, found in the anterior hypothalamus near the optic chiasm and third ventricle, is one of several sleep promoting nuclei that innervate the ascending arousal system (Zecharia, 2010) (see Figure 2-3). It is considered to play a particularly important role in the induction and maintenance of sleep by functioning as the transitional switch (Liu, Li, & Ye, 2010). This is despite the finding by Saper et al. (2010) that large VLPO lesions in rats had only a limited effect on sleep; a finding that suggests there are other systems implicated in suppressing the arousal systems and allowing sleep.

The VLPO mediates the sleep/wakeful state by suppressing the arousal system when prompted to do so by adenosine and serotonin afferents that up-regulate the release of inhibitory GABA and galanin, while the orexin system is thought to stabilize the sleep. More precisely, adenosine and serotonin act by up-regulating GABAergic and galaninergic neurons in the VLPO (Porkka-Heiskanen & Kalinchuk, 2011; Saper et al., 2010; Zecharia, 2010). Hayaishi (2011) holds the view that the onset of sleep begins in the basal forebrain with a PGD_2 mediated increase in extracellular adenosine. This initiates an adenosine-modulated signal that projects to and excites GABAergic and galaninergic neurons in the VLPO. When excited, these VLPO neurons inhibit the histaminergic tuberomammillary nucleus, and send GABAergic and galaninergic afferents to the locus coeruleus, the raphe system, periaqueductal grey matter, parabrachial nucleus, and lateral hypothalamus (Saper et al., 2010). Adenosine also acts by directly suppressing the wake-promoting histaminergic system of the tuberomammillary nucleus and the cholinergic system of the basal fore brain by binding to inhibitory receptors ($Adenosine_1$) (Deurveilher & Semba, 2011; Oishi, Huang, Fredholm, Urade, & Hayaishi, 2008).

Conversely, following sufficient consolidated sleep the VLPO receives inhibitory signals from the arousal system. Each of the monoaminergic groups including the histaminergic tuberomammillary nucleus that constitutes the wakefulness promoting system, projects to the VLPO, however, these two systems operate differently. The monoaminergic system inhibits the VLPO through noradrenaline and acetylcholine afferents acting on noradrenaline-excited and noradrenalin-inhibited neurons (Gallopin et al., 2005) while the histaminergic system is thought to increase the release of GABA onto noradrenaline-inhibited neurons, thus inhibiting the activity of these sleep promoting neurons (Liu et al., 2010; Saper et al., 2010; Zecharia, 2010). In this way, the VLPO can be inhibited by the very system it had inhibited.

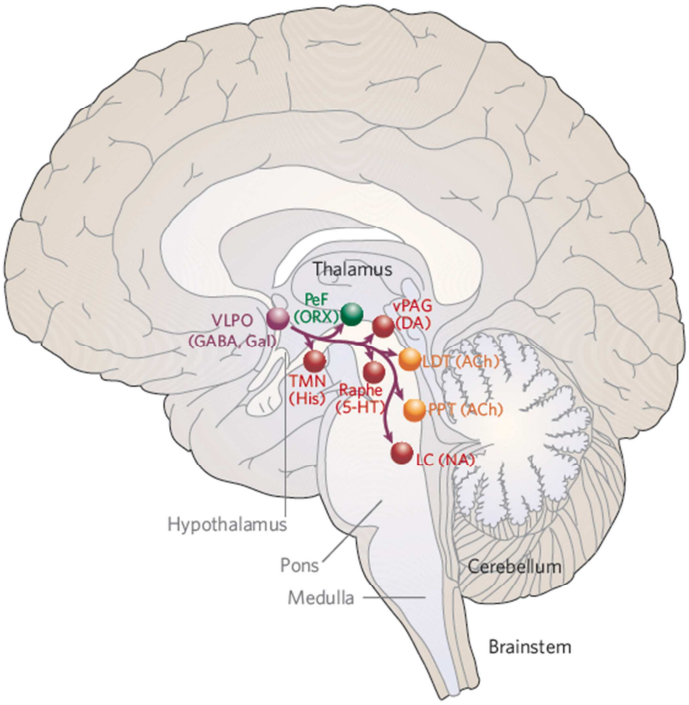

Figure 2-3 A schematic drawing showing main projections from the ventrolateral preoptic area to the ascending reticular network. The monoaminergic pathway is shown in red, orexin neurons are shown in green and cholinergic cell groups are shown in yellow. Ach, Acetylcholine; DA, dopamine; GABA, gama- aminobutyric acid; Gal, Galanin; His, Histamine; LC. Locus coeruleus; LDT, laterodorsal tegmental nucle; NA noradrenaline; ORX orexin; PeF, perifornical; PPT, pendunculopontine; raphe, dorsal and median raphe nuclei; TMN, tuberomammillary nucleus; VLPO, ventrolateral pre-optic area; vPAG, ventral periaqueductal grey matter; 5-HT, serotonin. From Saper et al. (2005).

2.5.6 *The Flip-flop Switch*

The interaction between the sleep and wake states has been recognised as being mutually inhibitory (Fuller et al., 2006; Gallopin et al., 2005; Hara & Sakurai, 2011; Saper et al., 2010). When each side is active it reduces its own inhibitory feedback and suppresses the counterpoised population of neurons in the other state. This is considered to be analogous to what has been described as a 'flip-flop' switch, a type of electronic switch that allows for a rapid and complete state change (Fuller et al., 2006; Saper et al., 2010; Zecharia, 2010). According to Saper, this type of switching mechanism should produce stable sleep and wake states thereby preventing an individual from falling asleep during a boring task, or wakening every time there is a small disturbance during the night.

A key feature of this switching process, is that the threshold, which an inactive state must cross before a transition from the counterpoised active state occurs, is higher than the threshold the current state must stay above in order to remain active (Saper et al., 2010). In other words, the high entry level necessary for a state change does not have to be maintained throughout, thus giving the current state an advantage. This asymmetry is thought to come about because sleep-promoting neurons in the VLPO must be sufficiently

excited so as to overcome the inhibitory effect of wake-promoting neurons. However, during sleep when the sleep-promoting neurons are no longer inhibited, they can continue to be activated by relatively weak stimuli, such as low levels of homeostatic drive. Eventually, the counterpoised wakeful state becomes sufficiently strong enough to breach the threshold necessary to suppress the sleep state, and a state transition occurs (Saper et al., 2010). This self-reinforcement helps to ensure an inherently stable sleep/wake state where one is either predominantly awake or asleep (Saper, Chou, & Scammell, 2001). However, as Fuller et al (2006) point out, 'either/or' switches possess the property of undesirable sudden state transitions (see also Saper et al., 2005). For example, a weakening of the arousal system could bias the switch more in favour of the sleep-inducing state. Where this occurs, smaller than normal perturbations could trigger a transition into the sleep state.

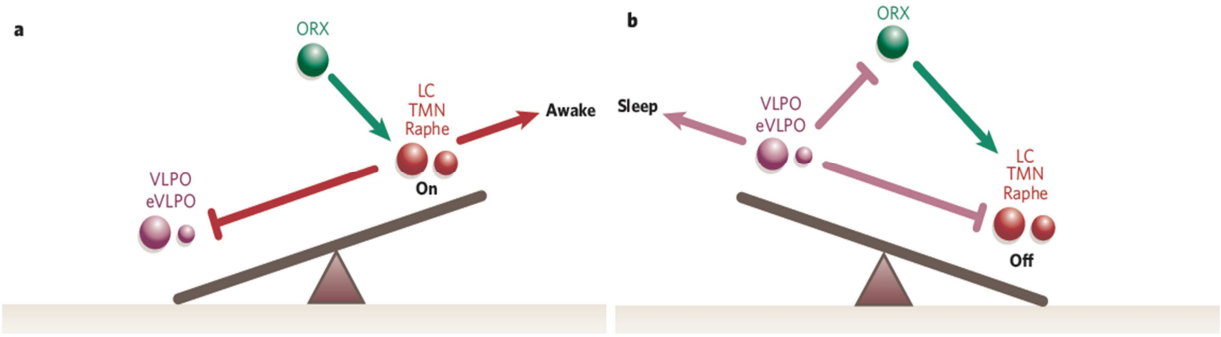

Figure 2-4 A schematic diagram of the flip-flop switch model. During wakefulness (a), monoaminergic nuclei (red) from the locus coeruleu (LC)s, tuberomammillary nucleus (TMN) and raphe nuclei inhibit the ventrolateral preoptic nucleus (VLPO; purple). During sleep (b), firing of VLPO neurons inhibit the monoaminergic cell groups, thereby relieving their own inhibition. This also allows it to inhibit the orexin neurons (ORX), further preventing monoaminergic activation that might interrupt sleep. This direct mutual inhibition between the VLPO and the monoaminergic cell groups forms a classic flip-flop switch, which produces sharp transitions in state, but is relatively unstable. The addition of the orexin neurons stabilizes the switch. eVLPO, extended ventrolateral preoptic nucleus. (Saper et al., 2005)

Although Saper and co-authors (2010) had suggested that the circadian, homeostatic, and allostatic drives (i.e., stress induced factors such as hunger, confrontation, or seasonal changes) were responsible for state transitions , Urade (2011) nominated the orexin system to be the finger on the switch. Regardless, in the transition to the wake state, orexin neurons that have been excited by efferents from the infralimbic cortex, the suprachiasmatic nucleus (SCN) and energy balance (between grehlin excitory inputs, and glucose, and leptin inhibitory inputs) excite monoaminergic neurons in the wake promoting arousal system. In turn this collection of nuclei sends excitatory afferents to the thalamus and onwards to the cerebral cortex. They also send inhibitory afferents back to the orexin neurons, and to the VLPO; thus stabilizing orexin neurons and quietening the VLPO's inhibitory action on both the arousal system. Conversely in the transition to the sleep state, excitatory efferents to the orexin neurons are reduced. Furthermore the orexin neurons receive a

strong inhibitory signal from VLPO GABAergic neurons that are also projected to the arousal system quietening monoaminergic neurons. When sufficiently powerful these two inhibitory signals shut down the arousal system (Hara & Sakurai, 2011; Sakurai, 2007).

Although the notion of a flip-flop switch suggests an either/or state; that would mostly be true for a single conduit circuit. However, because the neural pathways between the arousal system, the VLPO, and orexin neurons consist of many, possibly thousands, of neurons with differing inputs that must shift their activity, the transition from one state to another occurs over seconds to minutes with humans typically taking several minutes to completely reflect the state change (Saper et al., 2010). Nonetheless, the behavioural change can appear rapid because as Saper et al., point out, the rate of change is maximal at the inflexion point.

2.6 Microsleeps

2.6.1 *Behavioural Characteristics*

Microsleeps have, similar to attention lapses, been variously described. For example, Beck et al. (2010) used the term to refer to short periods of sleepiness or sleep between 15–30 s. Anderson et al. (2010) referred to any lapses with eyes closed as a microsleeps whereas a lapse with eyes open is either visual attention or distraction. Levitt (1967) referred to microsleeps as short periods of slow wave sleep. Attempts have also been made to define microsleeps using strict EEG spectral changes regardless of other overt behavioural indications (Harrison & Horne, 1996; Lim & Dinges, 2008; Peiris et al., 2006a). Harrison and Horne proposed that microsleeps could be indicated by spectral, topographical, and morphological changes, mainly by the predominance of EEG theta (4–7 Hz) activity. However, as noted by Boyle et al. (2008), there is a difficulty in using only EEG spectral power because muscle and movement artefacts can hinder EEG interpretation and because EEG interpretation is inherently subjective. Golz and Sommer (2008) noted that episodes of theta activity can occur without the necessary coincident lapse in responsiveness, which brings into question the validity of EEG spectral power change as being by itself a sufficient marker for a microsleep. Peiris and colleagues, attempted to use EEG spectral power, normalized spectral power and power ratios from the standard EEG bands to detect microsleeps but achieved only modest success. In another study, Peiris et al. (2006b); (see also Peiris et al., 2005) found that while spectral power was higher during lapses in the delta, theta, and alpha bands, and lower in the beta, gamma, and higher bands, the correlations between changes in EEG power and lapses were low.

Sommer et al. (2009) proposed a two-stage methodology for defining microsleeps. The first stage involved the identification of overt behavioural indications of sleep, such as prolonged eyelid closures, slow roving eye movements, head nodding, slow drifting head movements all of which are often followed by abrupt reactions. These episodes were then assessed using EEG, EOG, and eye tracking biosignals. Overlaps were defined as microsleeps while non-overlaps were referred to as non-microsleeps

However, the microsleeps of interest in this study are arousal-related lapses characterized by clear overt behavioural signs of either drowsiness, or sleep and a coincidental response disruption (Innes, Poudel, & Jones, In press; Peiris, Jones, Bones, & Davidson, 2007). Unlike that proposed by Sommer et al., there is no requirement that specific EEG, EOG biosignals be present. Nonetheless, these behaviourally defined microsleeps have been associated with widespread, increased bilateral activity in the frontal and parietal cortex, particularly the inferior frontal, pre-central, post-central, and superior parietal cortex during fMRI studies (Poudel et al., In Press). They have, by definition, a duration of 0.5–15 s with lapses greater than 15 s being classified as sleep. The behavioural signs are: full or at least 80 % eyelid closure accompanied by clear indications of drowsiness – which may include prolonged eyelid closure, slow roving eye movements, head nodding and slumped posture, all of which are sometimes followed by abrupt reactions – coincident with flat responses, where the subject has stopped responding to the task at hand. These behavioural signs are based on the criteria used by Wierwille and Ellsworth (1994) to identify severe drowsiness.

Microsleeps are thought to be the result of low arousal and attention levels being unable to counter the homeostatic drive for sleep, possibly as a consequence of low levels of bottom-up exogenous stimulation (Matthews et al., 2002a; Poudel et al., 2008b). They were studied by Peiris et al. (2006b) who during the early afternoon and under soporific conditions, tested the impact of a continuous, monotonous, visuomotor task on responsiveness. In a cohort of 15 healthy, male, non-sleep-deprived volunteers, they unexpectedly found frequent lapses in a substantial proportion of those who participated. Over two one-hour sessions, the average lapse rate – including tracking flat spots, video microsleeps (lapses evident by overt signs of drowsiness but no coincidental flat tracking response), and definite microsleeps – was 39.3 per hour (range 0–141.5 per hour). Notwithstanding, that these figures were generated by seated participants in a quiet room; Poudel et al (In press) also found that microsleeps were common in non-sleep deprived participants, but who were positioned supine in a confined and noisy environment of a fMRI machine. They tested 20 fit and healthy young adults and found that the mean microsleep rate per hour was 79 per hour (range 0–190). Of the 20 participants in this later study, 14 had at least 36 microsleeps during the 50-min tracking task, two participants had 1 and 2 microsleeps respectively, while four participants had none. They attributed the relatively high number of microsleeps to several factors, which included the monotonous nature of the continuous visuomotor task, the postprandial somnolence, and supine position of the contestants.

Importantly, the mean duration of the microsleeps experienced in Poudel's participants was 3.3 s (range 1.1–6.3 s), which is more than sufficient time to precipitate an event with serious consequences. Unfortunately, the underlying factors precipitating this form of lapse remain largely unknown. Poudel (2010) pointed out that several studies have investigated other forms of arousal-related lapses, but the literature on behaviourally defined microsleeps is relatively sparse. A search of PsychInfo using the search criteria 'microsleeps' generate only 37 results and PubMed 56, of which 12 entries defined microsleeps according to behavioural characteristics.

2.6.2 *Neurophysiology of Microsleeps*

In a recent study, Poudel et al. (In Press), combined both EEG and fMRI in a study that investigated microsleeps during a continuous task. The neural blood-oxygen-level-dependent (BOLD) activity decreased bilaterally in the midbrain, thalamus, posterior cingulate and occipital cortex along with small areas in the right prefrontal cortex and cerebellum during microsleeps. Activity increased strongly in the parietal regions encompassing the bilateral postcentral, superior parietal and supramarginal cortices and increased less strongly in the bilateral inferior frontal, precentral, parahippocampal, insular, temporal, occipital, and fusiform cortices during microsleeps (Poudel et al., In Press). Poudel and colleagues also investigated the time course of the BOLD signal in the thalamus and superior parietal cortex; the two structures that showed the greatest decrease and increase respectively during microsleeps. They found that thalamic BOLD activity started to decrease at or near the onset of microsleeps and mirrored the duration of the microsleeps with shorter microsleeps associated with a smaller amplitude decrease. Similarly, the size of the BOLD signal from the right superior parietal cortex also mirrored the duration of the microsleeps and again the shortest microsleeps were associated with the smallest amplitude change. Theta activity in the postcentral EEG correlated positively with the BOLD signal in the bilateral thalamus, basal forebrain, prefrontal, posterior cingulated, posterior parietal and visual cortices (Poudel et al., In Press).

While sleep deprivation is not necessary for the expression of microsleeps (Innes et al., 2010; Peiris et al., 2006b), sleep deprivation has been found to increase microsleeps propensity (Beck et al., 2010; Boyle et al., 2008; Moller et al., 2006; York, 2005). Innes et al. (In press) investigated intraindividual differences in microsleep counts when non-sleep deprived and when sleep deprived. They reported that the number of microsleeps during a 20 min monotonous task increased following sleep-restriction (mean 11.4 vs 27.9, p = .03). However, they found no evidence that the high rates of microsleeps observed in some of their non-sleep-deprived people were due to poor sleep quality, sleep disturbance, circadian type, irregular sleep patterns, low daily sleep duration, or poor sleep efficiency. Nonetheless, they did find that people who go to sleep at a regular time, fall asleep easily, and sleep efficiently are more likely to be adversely affected by sleep restriction as evidenced by frequent microsleeps. This they ascribe to a greater vulnerability by those participants to the effect of limited time-in-bed and/or delayed sleep onset time.

However, there is an absence of literature on the effects of tasks on microsleeps. A search of PubMed and PsychINFO did not reveal a single paper that examined the impact of the task on microsleeps. All behaviourally-defined microsleep studies have used a continuous tracking task in which the difficulty was kept constant and no comparisons were made between variations of the task in order to understand what, if any, impact the type of task might have.

Chapter 3. Study of Lapses and Task Type

3.1 Introduction

Momentary lapses of responsiveness frequently impair goal-directed behaviour, and the literature underpinning research into these lapses of responsiveness has generally referred to them as sustained attention lapses. Currently, this literature is divided between two competing theories. On one hand, there is the mindlessness theory (Manly et al., 1999) and, on the other, the resource depletion theory (Helton et al., 2005; Helton & Warm, 2008; Smit, Eling, & Coenen, 2004a). . Mindlessness theorists propose that attention lapses result from the subject disengaging from the task due to the task's monotony and low exogenous support for attention (e.g., Robertson et al., 1997). Conversely, the resource depletion theorists propose that attention lapses arise because demands for attentional resources outstrip supply, which leads to substantially delayed response and/or errors (Warm & Dember, 1998).

However, there are other types of lapses that the literature has not always clearly separated from lapses of attention. One such type of lapse is the microsleep. Microsleeps are brief periods of non-responsiveness (0.5–15 s) associated with overt signs of drowsiness (Peiris et al., 2005). Although the two theories of lapses of attention provide contrasting explanations in the traditional vigilance literature, neither theory addresses lapses due to microsleep events, which remains largely ignored.

Microsleeps are reported as being distinctly different from attention lapses, both physiologically and behaviourally (Poudel, 2010). Nonetheless, they are far from being disassociated constructs. Microsleeps are thought to emanate from a homeostatic drive for sleep/rest and a complex interaction between the brain's arousal and attention systems (Poudel, 2010). This suggests that the type of task being undertaken is likely to modulate a person's propensity for microsleeps. For example, it is possible that engagement in a task that is more demanding would counteract the otherwise homeostatic drive for sleep and rest. If true, tasks that increase cognitive workloads may lead to a reduction in microsleeping propensity.

In this study, we sought to differentiate the mindlessness theory from the resource depletion theory and sought to differentiate the effect of task on microsleep propensity by varying tasks. We achieved this by monitoring the behavioural response of a group of participants while they undertook three tasks representing different task type and presumed cognitive workloads. The tracking task that was used was similar to the 2-D visuomotor pursuit tracking task previously used by Poudel et al. (2008a). It involved the subject continuously tracking a target moving in a pseudo-random 2-D pattern using a floor-mounted joystick. A discrete task, referred to as the PVT task, was a one-choice reaction-time task. It was similar to the standard PVT as proposed by Dinges and Powell (1985) in which the subject responded as quickly as possible when they recognised a response signal that was randomly presented. The third task completed was the dual task. It was a combination of the tracking task and the PVT task and provided a contrast

between cognitive workloads and exogenous stimulation. It also provided a common link between the other two tasks. Therefore we were able to make two comparisons. We could compare PVT results from the PVT task with the results from the PVT assignment in the dual task, which was completed under an increased cognitive demand; and we could compare microsleeps that occurred during the tracking task with microsleeps during the dual task.

From this monitoring, instances of a flat response (a cessation of joystick movement), tracking errors, and response times to the PVT were collected. In addition, video recordings of the participant's face was synchronously recorded (see Figure 3-1 for the laboratory layout showing the position of the video camera, the visual display unit, the floor-mounted joystick and the seating position of the participant).

A counterbalanced repeated-measures design was used to collect intraindividual results, which were analysed for differences in performance of the three tasks. The order of the three tasks was counterbalanced by randomly assigning one sixth of each gender group, constituting the participants, to each of the six order combinations. Both parametric and non-parametric processes were used in the analysis of the results.

3.2 Study Requirements

There were three key requirements for this study. The first, and primary, requirement was to set up a paradigm that would demonstrate cause and effect between the independent variable, which was the type of task, and the dependent variable which was the form of lapse. Having determined that this requirement could be met by measuring behavioural responses, characteristic of lapses, during the performance of three different tasks there were a further two secondary requirements.

The first was a system to simultaneously record synchronized visuomotor responses (i.e., tracking and reaction times) with eye and head video recording during performance of the three tasks. The second requirement was a procedure that would allow for the identification of *microsleeps* and *attention lapses* using visuomotor responses and video recordings, which could also facilitate the investigation of lapses and their characteristics.

3.3 Hypotheses

Hypothesis 1

Question: Does the addition of a task requiring high short-term effort, such as the PVT, to a continuous monotonous task, such as the tracking task, increase the frequency of attention lapses, which on one hand are theorized to be the result of high levels of cognitive demands leading to the depletion of cognitive resources; or will it decrease the frequency of attention lapses, which on the other hand are theorized to be the result of mindlessness?

Hypothesis: The dual task will induce more attention lapses than the PVT task alone.

Rationale: The dual task, in which the tracking task is combined with the PVT task, is theoretically a more cognitively demanding task than either of the two tasks taken by themselves (Matthews & Davies, 1998; Wood, 1986). Therefore, the additional cognitive demand should exacerbate the depletion of cognitive resources and, therefore, according to the resource depletion theory, lead to an increase in the frequency of attention lapses.

Significance: If increasing the cognitive demand leads to more lapses of attention this would be an important result by itself. It will also provide support for the resource depletion theory as a theoretical framework for understanding some types of lapses. Conversely, if there were no difference in the frequency of attention lapses this would suggest that attention lapses are not mediated by resource demands. Furthermore, if increased cognitive demand leads to fewer attention lapses this would indicate support for the mindlessness theory of lapsing**.**

Proposed study: A comparison will be made between the behavioural responses elicited during the dual task with the behavioural responses elicited during completion of the PVT task.

Hypothesis 2

Question: Does the random addition of an extra stimulus, such as provided by the PVT to a continuous monotonous task, enhance task engagement and therefore result in fewer microsleeps?

Hypothesis: The dual task will induce fewer microsleeps than the tracking task alone.

Rationale: Microsleeps reported in the tracking task are thought to be the result of low levels of cortical arousal. Adding the PVT assignment, which is theorized to generate energetic arousal, to the tracking task should help to increase arousal and therefore lead to fewer microsleeps.

Significance: The significance of knowing that microsleeps are more likely to be the result of continuous monotonous tasks than those with sudden onset and offset stimuli will provide support for the mindlessness as a theoretical framework for understanding some types of lapses.

Conversely, no difference in microsleep rate between the two tasks would indicate that microsleep frequencies are not moderated by task type but, instead, are task independent. Additionally, if the frequency of microsleeps is higher during the dual task, this would suggest that the associated increase in resource demands increased microsleeps and that the resource depletion theory is the appropriate theoretical framework by which to understand them.

Proposed study: A comparison will be made between the behavioural responses elicited during the dual task with the behavioural responses elicited during completion of the tracking task.

3.4 Methods

3.4.1 *Participants*

Psychomotor performance data were collected from 24 participants aged between 18 and 45 years (mean age = 26.25, range 21–40). The 12 females and 12 males were recruited from the University of Canterbury, the New Zealand Brain Research Institute, and the general public. Participation in the study required all participants to meet the inclusion criteria listed in Table 3-1 and provide their informed consent (see Appendix A).

Table 3-1 Inclusion criteria for participation in study.

Inclusion criteria.
Aged between18–45 years
Right-handed
No history of psychiatric, neurological, or sleep disorder
Usual time to bed between 10 pm and 12 pm
Usual sleep between 7 to 8.5 hours
Epworth daytime sleepiness score < 10
Reasonable ability in English (verbal and written)
Not sleep-deprived prior to the experimental sessions
Normal visual acuity
Willingly given their informed consent to participate

As a part of the screening process, information on the subject's current neurological, psychiatric, and sleep status was obtained during a personal interview. Demographic and other personal information from all participants (age, ethnicity, Pittsburgh Sleep Quality Index, Epworth Sleepiness Score, and general health) were also obtained via a questionnaire which can be found in Appendix B.

Sample size

A sample size of 24 was selected as providing an appropriate balance between power calculations and resources. Using G Power it was calculated that a group this size has 80% power for detecting an effect size of 0.8 using a two-tailed test based on an asymptotic relative efficiency distribution, with alpha set at .05 (Lipsey, 1998).

Sampling Error

One participant (male) had an extreme number of microsleeps in both the tracking task and the dual task (65 and 83 respectively). These two data points are so far outside the norm for this population ($z = 4.5$) that they were considered to be outliers (Osborne & Overbay, 2004). Moreover, an examination of this participant's response to the sleep questionnaire found that in the week prior to the study, he did not retire for sleep until 1:30 am and was only averaging 6 hours 30 min in bed, which (contrary to what was first accepted) was

outside of the inclusion criteria. According to Van Dongen, Maislin, Mullington and Dinges (2003) there are high sleep deprivation costs when sleep is restricted. Therefore, this participant's results were removed from the study because we were not confident that the excessive number of microsleeps was not the result of sleep deprivation.

3.4.2 *Experimental Setup and Equipment*

This study was conducted in a room measuring approximately 5.5m x 3.2m. The room had no windows and, for the purpose of this study, was lit by a single 40 watt incandescent light bulb during the test sessions. Ventilation was provided by an air conditioning unit with the room temperature set at 22 deg C.

Figure 3-1 Photo of the participant's workstation, showing the floor-mounted joystick, the video recording camera, and the stimulus visual display unit. During the experiment the door into the adjacent room was closed.

The participant's workstation consisted of a small desk that faced a blank wall. It held the stimulus visual display unit and video camera (see Figure 3-1). The participant sat in a chair placed in front of the workstation with the floor-mounted joystick located between their legs approximately in line with their knees. Immediately and approximately 700 – 800 mm front of and facing the participant was the stimulus visual display unit. The top of the screen was approximately level with the participant's line of sight. The video camera was mounted on a tripod directly behind the screen and the camera positioned so that it framed the participant's face and shoulders. To the left of the participant, and out of their line of sight was

located the researcher's workstation which contained the stimulus computer, researcher's visual display unit, keyboard and mouse.

Test program

A Delphi-based computer program SMCTests™ generated the three tasks required by this study. This program had been developed for the quantitative assessment of upper-limb sensory-motor and cognitive functioning (Innes et al., 2007), and was subsequently modified for this study to generate the discrete PVT task.

The *SMCTests*™ program was run on a desktop computer employing a Windows platform. The computer (i) generated and displayed the target disk used in the tracking and dual tasks (the red disk in Figure 3-7), and displayed the stimulus counter used in the dual and PVT tasks, (ii) sampled the joystick response, which it then displayed as the response disk to provide feedback to the participant (yellow disk Figure 3-7), (iii) stopped the counter when the offset button on the joystick was pressed and calculated reaction times for each PVT trial . It also stored as Matlab '.mat''.txt' files the stimulus and response data from both the tracking and PVT tasks for offline analysis.

The stimulus visual display unit was a 17-inch LCD flat screen colour monitor manufactured by Viewsonic (Walnut, California, USA). It had a screen resolution set at 1024 x 768 px and was refreshed at 60 Hz.

Eye-video recording

The video recording was made with a Sony Handy Cam model HDR XR200E (Tokyo, Japan) using its 'Nightshot' setting. When used in this setting the camera emitted an infrared light, which enhanced the image quality that otherwise would have been poor because of the low light setting in the laboratory. It uses an AVCHD (Advanced Video Coding High Definition) format with a '.m2ts' filename extension for its movie files and has a capture rate of 50 fps.

In order for the files to be used by SyncPlayer ™ the AVCHD format used by the camera needed to be converted to Quicktime h264 '.mov' format.. This conversion was made using a video format converter software (iSkysoft Video Converter, Version 2.3.2; Guangdong, China).

SyncPlayer™.

The synchronized recordings were viewed via SyncPlayer ™. SyncPlayer ™ is a software program written for a previous study (Poudel et al., 2010). It was used to synchronize and display via two separate windows; video recordings, and tracking signals (see Figure 3-2). It was subsequently modified to also display in the tracking signals window, stimulus onset and offset times related to the discrete task.

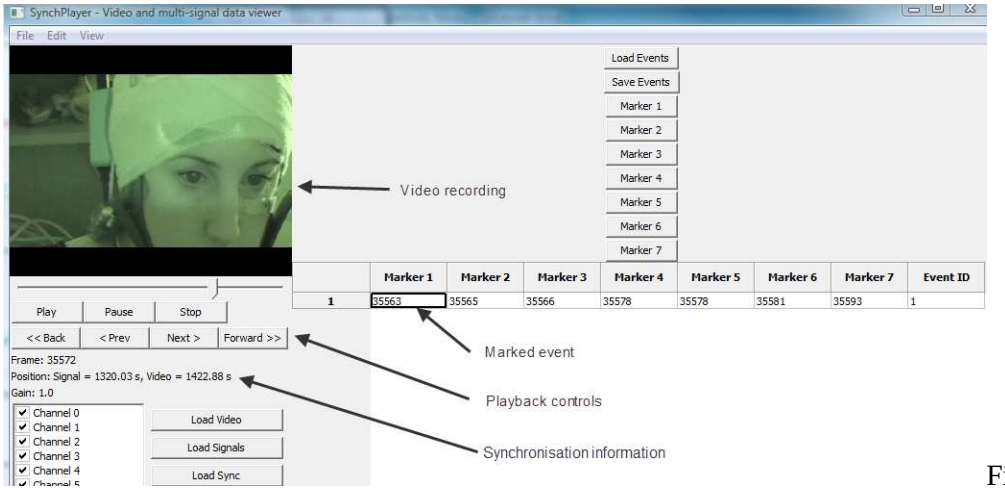

Figure 3-2

Figure 3-2 Partial screen shot of the SyncPlayer™ window.

The program uploads the screen coordinates of the response and target disks previously saved in MatLab '.mat' files and displays the x and y-axes of the response signal overlaid on the target signal. It also calculates and displays the tracking error, the resultant speeds of the response signal overlaid on the target signal, and displays the discrete task stimulus onset offset times (see Figure 3-3).

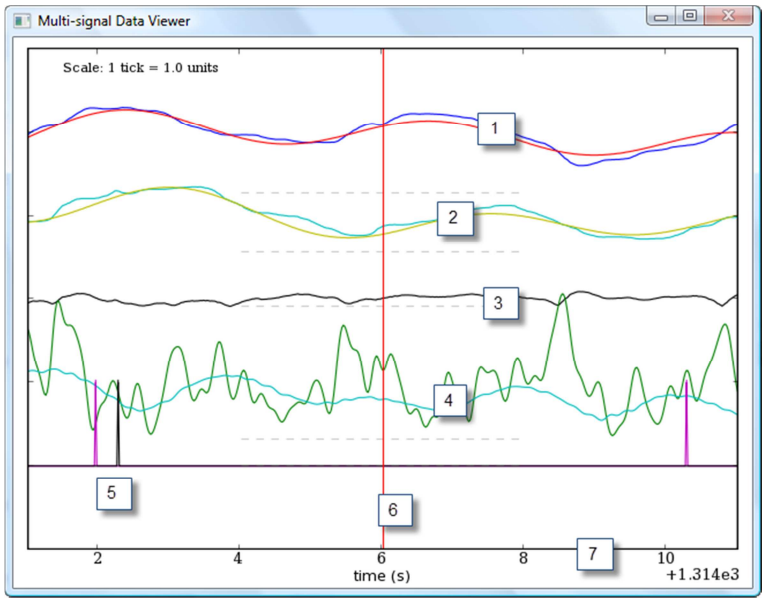

Figure 3-3 A screen shot of the Multi-signal data viewer window used in conjunction with the SyncPlayer window to identify events. (1) X axis position of the target and response cursors. (2) Y axis position of the target and response cursors. (3) Tracking error. (4) Required and actual joystick speed. (5) Onset (purple) and offset (black) of a PVT stimulus. (6) Video frame reference line for the position signal displayed in the SyncPlayer window. (7) Timeline.

In addition to its display function, the program has a function that allows the recording of four different event types each with up to seven markers. The seven markers used are listed in Table 3-2 below and were

those used previously by Poudel (2010). Each mark locates the event by recording the associated video frame number.

Table 3-2 Description of the seven markers used to record an event. Each mark was made by recording the associated video frame number.

Marker Identity	Marked Event
Marker 1	Start of poor or flat/incoherent tracking including start of rise in error, or start of speed ~ 0
Marker 2	50% of full eye-closure (where available) based on either video recording or VEOG.
Marker 3	Start of full eye closure (where available) based on either video recording or VEOG.
Marker 4	Completion of full eye closure (where available) based on either video recording or VEOG.
Marker 5	50% of eye open (where available) based on either video recording or VEOG.
Marker 6	Full eye open (where available) based on either video recording or VEOG.
Marker 7	End or poor or flat/incoherent tracking including end of flat spot, start of speed > 0, or start of coherent tracking

Floor-mounted joystick

The floor-mounted joystick shown in Figure 3-4 was purpose built for the study by the Department of Medical Physics and Bioengineering, Canterbury Health Board, New Zealand. It has a lateral movement of approximately 30^{o} from the vertical in all directions, which for the average person meant at the hand position a circle of movement with a radius of 225 mm.

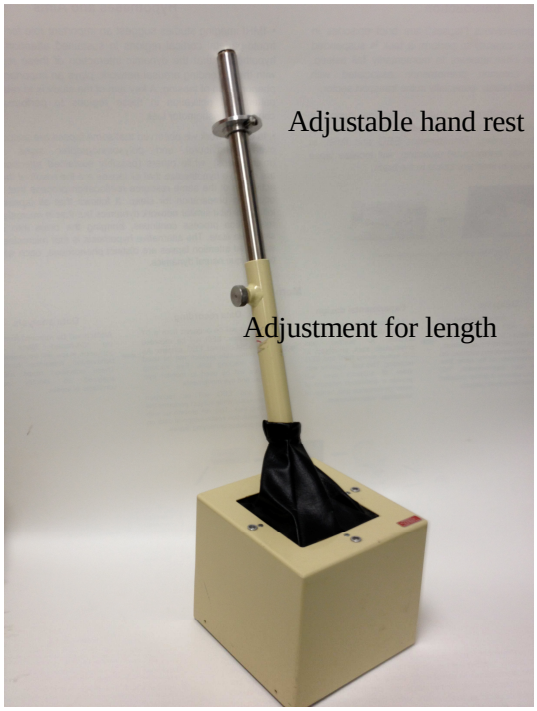

Figure 3-4 The Floor-mounted joystick. The height of the joystick and the collar used as a hand rest can be adjusted to suit the user.

Figure 3-5 The response button for the PVT stimulus shown located on top of the joystick where it is easily activated by the thumb.

The top of the joystick contains the response button for the PVT stimulus (see Figure 3-5). It was used to respond to the PVT stimulus. Its position on top of the joystick was readily accessible by the participant using their thumb. To activate the switch the participant was required depress the switch approximately 0.5 mm which required them to exert an approximate force of 6 N to overcome the switch's inherent resistance. Analysis of the tracking data demonstrated that the button could successfully be depressed without adversely affecting the movement of the joystick. Nonetheless, there were instances where the rapid depression of the switch resulted in a brief ballistic movement of the joystick that was reflected in the tracking response. Conversely, there were no participants for who depressing the button always resulted in errant tracking.

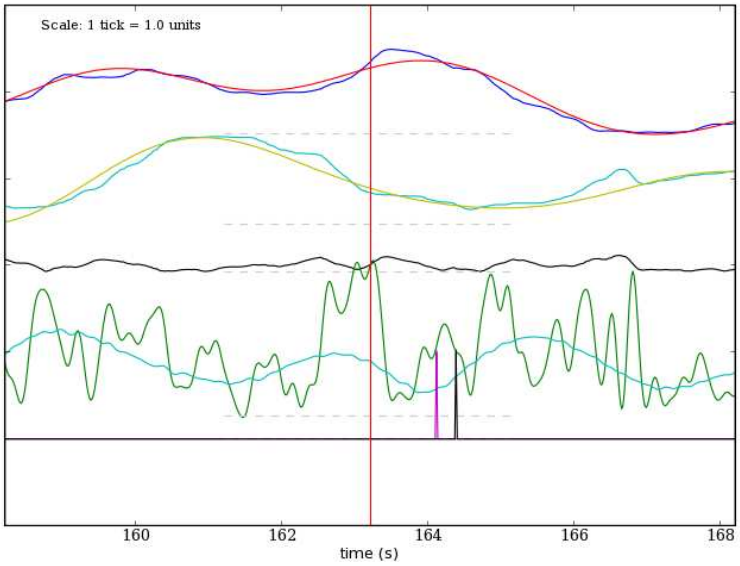

Figure 3-6 A screen shot from SyncPlayer showing a relatively fast reaction time to a PVT trial. Note that the tracking error at completion of the PVT trial has not been adversely affected through activation of the switch on the joystick. Although common, accurate tracking throughout a PVT trial did not always occur. There was also evidence of ballistic movements resulting from the rapid depression of the switch.

3.4.3 *Tasks*

The study design required the completion of three 30-min. tasks – the tracking task, the PVT task, and the dual task. The tracking and PVT tasks represent two distinct types of visuomotor task: the continuous task and the discrete task respectively. The dual task provided a contrast between cognitive workloads and levels of exogenous stimulation. These three tasks allowed for two sets of comparisons to be drawn. One comparison was of tracking data from the tracking task and the dual task and the second comparison was of vigilance data from the PVT task and the Dual task. The task order was counterbalanced. This provided for six orders each with a different sequence of tasks (Table 3-3). Each order had two female and two male participants randomly assigned to it; with the exception of Order 2 – tracking task, dual task, PVT task – which had three male members due to the late removal of one participant (see Outlier Treatment and Over Dispersion in the Discussion section)

Table 3-3 The six orders show each unique sequence of tasks.

Order	Sequence
1	Tracking task, PVT task, dual task
2	Tracking task, dual task, PVT task
3	PVT task, tracking task, dual task
4	PVT task, dual task, tracking task
5	Dual task, tracking task, PVT task
6	Dual task, PVT task, tracking task

Tracking Task

The tracking task was the same as that developed by Poudel and colleagues to detect microsleeps (Poudel et al., 2008a) Its suitability is reflected by: its monotonous nature, which is conducive to microsleeps; the ability to detect, identify and measure motor performance with high temporal accuracy; that both eye behaviour and head movement could readily be videoed; and performance metrics could readily be synchronized with both EEG and the video data with millisecond accuracy.

During this task, the participant was required to use a floor-mounted joystick to voluntarily track a moving target that tracks, without any flat spots, across a visual display unit in a 2-D pseudorandom manner – i.e., the target was always moving with a minimum speed. Tracking performance was recorded at a sampling rate of 60 Hz by the *SMCTests*™ program for later analysis. Any lack of visuomotor responsiveness would become evident because of either incoherent tracking or the presence of flat spots due to a lack of joystick movement.

The target was a yellow disc with a diameter of 7.8 mm. It had a trajectory period of 30 s that was repeated 60 times to extend the task to a 30-min period (Figure 3-7). The trajectory prescribed by the target disk was defined by summing seven sinusoids with frequencies evenly spaced between 0.033 to 0.231 Hz for both the vertical and horizontal vectors of the target. Poudel et al. noted that a bandwidth of 0.231 Hz would provide a moderately challenging task during baseline tracking and a specific set of random-phase shifts in the vertical and horizontal components and results in a trajectory that was largely unpredictable. It also results in the target with a velocity range between 63–285 pixels per second – i.e., the minimum target is near stationary. Feedback was provided to the participant by means of the red disk with a diameter of 6.6 mm (Figure 3-7).

Tracking accuracy was assessed by the tracking error, which is the Euclidean distance, measured in pixels, between the centre of the response marker and that of the target. Tracking error was calculated at 60 Hz (approximately every 17 ms). Ideally the centres of both markers would be in identical positions with zero distance between them as the participants were instructed to track the target marker as closely as possible. Therefore, assuming a participant's intention was to comply, any discrepancy in the position of the target marker and the response marker is a measure of that person's visuomotor performance.

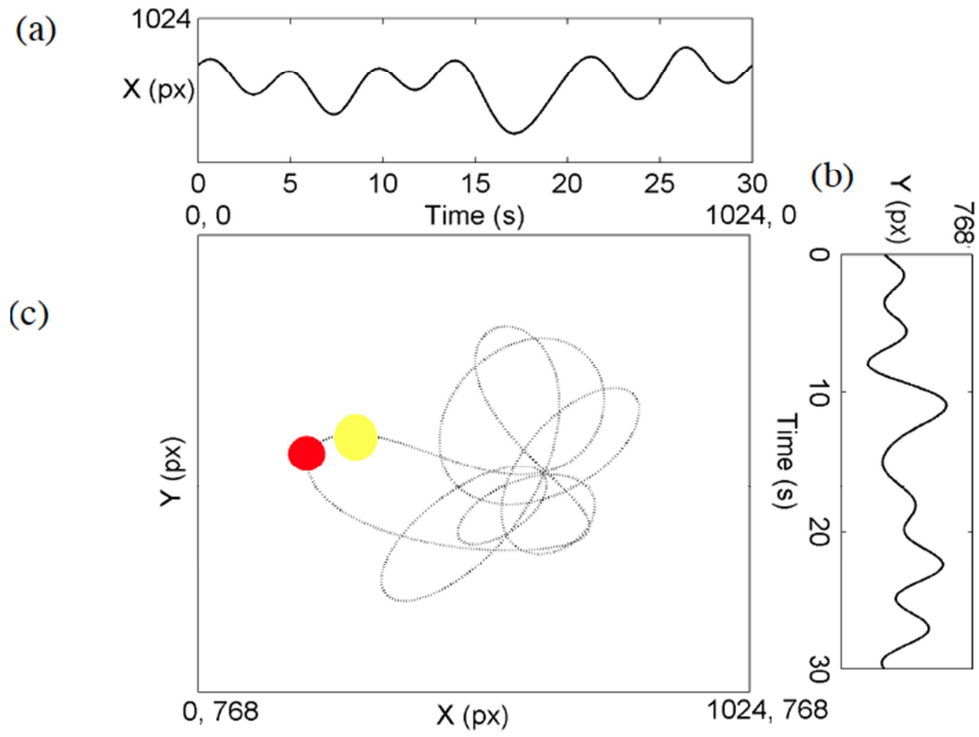

Figure 3-7 2-D continuous pursuit tracking task. The trajectory of the target (c), traced by the yellow dot, was the result of summing seven sinusoids in two dimensions (a and b). The red dot is the response cursor and provides visual feedback to the performer (from Poudel et al., 2008a).

Psychomotor Vigilance Task

The psychomotor vigilance task (PVT) used in this study is similar to the standard PVT proposed by Dinges and Powell (1985). It is a reaction-based task that requires a participant to respond to a visual stimulus, which appears randomly variable, with an inter-stimulus period of 2–9 s. The stimulus used in this study was a numeric counter in the middle of the stimulus visual display unit that changed at every screen refresh (60 Hz) and displayed the time in ms since its appearance (Figure 3-8). The stimulus continued to change until the push-switch on top of the joystick was activated. The stimulus – i.e., the time taken to respond – then remained visible for a further 500 ms to provide feedback to the participant on their performance on that trial.

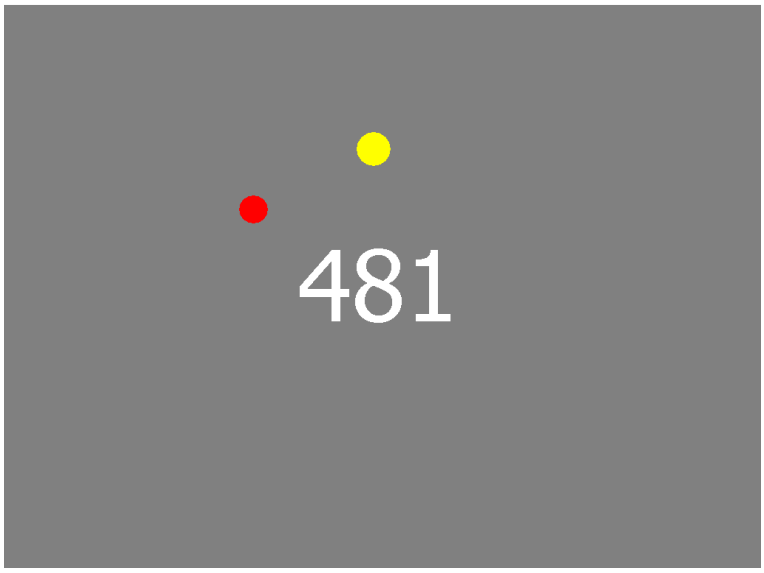

Figure 3-8 A screen shot of the dual task as it appears on the stimulus VDU. The yellow disk is the target and the red disk the tracking response. The white number is the stimulus for the PVT. It first appears as a zero and then counts upwards in ms until the push-switch button on top of the joystick has been pressed. The stimulus during the PVT task alone is the same but without the two moving disks being present.

Since being proposed by Dinges and Powell (1985), the PVT has become a standard assay of attention, particularly in sleep studies (Ratcliff & Van Dongen, 2011; Veasey, Rosen, Barzansky, Rosen, & Owens, 2002). During the PVT, a number of trials are completed in which the participant reacts as quickly as possible to a stimulus. This reaction time can be partitioned into two parts; time due to task demands, i.e., time required to physically complete the task, and time due to attention requirements. An implicit assumption of the PVT is that it is the variability in attention, not task demands that cause reaction times to exceed the 500 ms threshold (e.g. Belenky et al., 2003; Dinges & Powell, 1985).

By convention, reaction times in excess of 500 ms following the presentation of the PVT stimulus are arbitrarily considered to be lapses of attention (Anderson et al., 2010; Belenky et al., 2003; Chee & Choo, 2004; Graw, Krauchi, Knoblauch, Wirz-Justice, & Cajochen, 2004; Loh, Lamond, Dorrian, Roach, & Dawson, 2004; Ratcliff & Van Dongen, 2011; Van Dongen, Maislin, Mullington, & Dinges, 2003). In this study we have conformed to this convention and adopted the ubiquitous 500 ms as the threshold for determining the presence of an attention lapse.

Correction of Reaction Times from the Dual Task

The design of this study required reaction times to be measured during two different tasks, the PVT task and the dual task that differ, not only in task complexity, but also in their necessary responses. As a consequence, it was expected that reaction times on average would be longer during the dual task than during the PVT task because the dual task required the participant to physically and mentally complete two

assignments at the same time. Accordingly, to enable a comparison between the two sets of sustained attention lapses it was necessary to apply a validated correction to the dual task reaction times.

It was proposed that in physically low fatiguing tasks, such as the PVT and dual tasks used in this study, the portion of the response time incurred by task demands (i.e., the physical mechanics of completing the task), as opposed to attentional factors would remain relatively constant over multiple performances of the task, because the task and its application did not change. In other words, if attentional factors are held constant, then a reaction time from the beginning of a 30-min dual task should be similar to other reaction times made during the course of the task because neither the task nor the conditions under which it were completed, have changed. It then follows, that the variability in reaction times must be due largely to the variability of attention requirements and not because of any variability inherent in the task demands. Therefore, the best conservative estimate of the difference in reaction times due to task demands will come from the fastest reaction times as these times are the least affected by attention factors.

Accordingly, the correction is the difference between the means of the fastest 10% of reaction times from each participant per task (excluding reaction times less than 180 ms that are assumed to be false starts). This correction will be applied by subtracting it from all reaction times acquired during the dual task.

3.4.4 *Procedure*

Participant Sessions

There were two sessions in this study. The first session was an opportunity for the participant to familiarize themselves with the facilities and the procedure. Familiarisation was considered to be an important means of reducing exogenous stimulation and pre-test stress due to the novelty of finding their way to the laboratory, the newness of the surroundings and procedures. The second visit was the test session.

The first session was scheduled for the day prior to the test session. During this visit, the participant was given a tour of the facilities at the NZBRI, where they could see and learn more about the study and its objectives, see the equipment used, and experience the three tasks. The study's objectives were explained to them along with a detailed explanation of the procedure. Included in this briefing were details and explanations of the procedure including how overt behavioural signs of eye closure and head position would be recorded and how that and the tracking and response data would be used and protected. There was also an opportunity during this visit to sit at the workstation, view the surroundings, and manipulate the joystick. The visit was concluded with a reminder to observe normal sleep patterns and refrain from stimulants prior to the test on the following day. Caffeine and other stimulants as well as recent physical activity can promote alertness and importantly influence vigilance performance (Ruijter et al., 2000). In particular, coffee is a well-known stimulant, and promotes wakefulness by blocking adenosine receptors (Franke, Lieb, & Hildt, 2012; Lazarus et al., 2011; Luciano, Kirk, Heath, & Martin, 2005; Nehlig, 2004; Stafford, 2003). Conversely, a warm ambient temperature, and recent food intake are conducive to sleepiness and can have a detrimental effect on neurobehavioural performance (Veasey et al., 2002). Accordingly, because high-

glycemic meals have been shown to facilitate sleep onset (Afaghi, O'Connor, & Chow, 2007), each participant was provided with a high-glycemic meal consisting in part of white bread (known to have a high glycemic index Atkinson, Foster-Powell, & Brand-Miller, 2008) 30 mins prior to the session. In addition, the test was scheduled to occur during the early afternoon to take advantage of the postprandial somnolence most people experience following a midday meal (Bazar, Yun, & Lee, 2004). This period also coincides with one of the circadian dips in each day.

Although several factors, such as time-of-day, restricted caffeine intake, and pre-session lunch, may have increased the likelihood of arousal-related degraded performance, it is important to emphasize that the current study was not designed to directly investigate the influence of any of these factors on the frequency of microsleeps. Rather, these factors were deliberately chosen to increase the likelihood of microsleeps so that they could be studied.

After lunch, the participant was prepared for the tests. This began with a brief explanation of the procedure and confirmation of consent. To ensure that the procedure was clearly understood, the principal investigator discussed the information sheet (see Appendix A) with the participant who was again reminded that they were free to withdraw at any stage. Following this the participant was seated at the workstation.

Seating and placement of the joystick, and alignment of the video screen were confirmed before the beginning of each test. Full movement of the joystick was checked. The participant was seated 700–800 mm away from the stimulus screen with the floor-mounted joystick placed between the participant's legs. The height of the joystick was adjusted so that the forearm was parallel to the resting leg with feet placed flat on the floor. Included in the adjustment of the joystick was an adjustment of the collar that provides a hand rest so the thumb could comfortably reach and depress the button located on top of the joystick. The stimulus screen was set such that the top of the screen was horizontal with most participants' eyes.

The video camera was located behind the stimulus screen and high enough to allow the participant's eyes to be recorded unrestricted. The lens was adjusted so that the face was maximally framed yet would allow the eyes to remain framed after allowance for expected head movement (see an example in Figure 3-2).

Each task was preceded by a practice session for that task. In addition, the participant was briefed on the requirements of that task (see heading 3.4.3 for a detailed description of the task requirements) and any questions they may have had concerning the procedure were answered. The participant then practised the task for one minute with instruction provided when and if required. The practice session was successfully completed if at the end of the run the participant had been able to demonstrate competency in performing the task and had confirmed they understood the requirements for that particular task.

Before beginning the trial, it was necessary to provide a means of later synchronising the video camera recording with the response data recorded by *SMCTests*™ program. This was achieved by completing a recognisable action, both prior to and on completion of each task, capable of being recorded simultaneously by the video camera, and the *SMCTests*™ program. This process consisted of two procedures. The first

was to commence the recording and then ask the participant to blink five times while looking at the camera. This sequence of blinks was readily identifiable as were the video frames capturing the onset of the blinks. Furthermore, when the participant blinked they contracted the orbicularis oculi muscle that created a measureable electrical impulse. This impulse was able to be detected by bipolar Ag–AgCI sintered electrodes placed above and below the centre of the left eye and connected to a Compumedics NeuroScan EEG system which stamped the time log used by *SMCTests*™. In the second procedure, the researcher activated an infrared LED coincident with the blinks that was recorded by the video camera. Furthermore, activation of the LED simultaneously created an electrical impulse that was recorded in the *SMCTests*™ time log. By identifying the video frame numbers associated with the blink onsets and the start of the LED illuminations and correlating those frames with the respective *SMCTests*™ time log entries, it was possible to write a Matlab script that SyncPlayer could use to synchronize the playback of the video recording within microsecond accuracy of the response data.

During the recording, the researcher remained in the room but sat quietly at the researcher's workstation out of the line of sight of the participant. The 30-min recording session was concluded by a further five eye blinks as a part of the synchronization process.

Each of the first two tasks was followed by a 15-min rest period during which the participant was free to move around but not lie down or nap. Typically, a participant would remain seated at the workstation, but stretch their body, drink water and talk to the investigator. The purpose of this rest break was to provide both mental and physical relief from the just completed task. At the completion of the third and final task the rest period was substituted by a debriefing where the participant was debriefed on their performance and they were given an opportunity to ask and have answered any questions that they might have had concerning the study.

Confidentiality and Protection of the Data

All data collected for this study and retained on computer databases has been depersonalised with the exception of video files containing face, head, and shoulder images. All data files are stored on secure servers located at the Brain Research Institute, and on a secure password protected hard drive retained by the researcher. All hard-copied files including consent forms and completed questionnaires are secured in a locked cabinet.

All participants agreed to the video recording of face head and shoulders and for the data captured during the course of this study to be used for this and future studies provided those studies meet Ethic committee requirements.

3.4.5 *Analysis*

3.4.5.1 Event Classification

Events were identified and classified using a visual rating protocol developed by Poudel, et al. (In Press), which in turn was based on the work of Peiris et al. (2006b). It involved a visual inspection of the synchronized response and video data to identify a set of predefined characteristics unique to each of four event types (see Table 3-4). The events were rated following instruction by an expert rater familiar with the procedure used by Poudel et al. The identification of a PVT lapse could be made objectively using system recorded data.

Table 3-4 Event types and characteristics used for the classification of behavioural responses

Event Type	Characteristics
Drowsiness-related impaired responsiveness event – DIRE	Epoch of poor, but not incoherent tracking relative to baseline tracking for more than 500 ms accompanied partial eye closure but not full eye closure (other than blinks).
Microsleep	Flat or incoherent tracking for more than 500 ms but less than 15 s; and full or >80% eye closure (phasic/transition) with clear behavioural indications of drowsiness.
Lapse of task-oriented attention	Voluntary eye closure (e.g., temporary relief from fatigue) more than 500 ms, accompanied by flat or incoherent tracking for more than 500 ms that can partially be compensated for through predictive motor planning Or, or partial diverted attention due to extraneous activity or focus when either alert or drowsy with the absence of eye closure (apart from normal blinks)
Sustained attention lapse	Flat or incoherent tracking for more than 500 ms and no eye closure other than normal blinks and not directly related to the participants level of arousal and, hence, can occur when alert, or fatigued, or drowsy

The distinction between microsleeps and sleep based on duration is arbitrary, but according to Poudel (2010) they are considered to be physiologically different because of the recovery of responsiveness period which is much shorter in a microsleep. Therefore, events longer than 15 s, which would otherwise have met the criteria for microsleep, were considered to be 'sleep'.

The rating protocol used the following definitions:

Drowsy behaviour – Overt signs of drowsiness included drooping of the upper eyelids and the appearance of a "glassy" stare and a loss of proper vergence due to possible occulomotor fatigue (Kiettmann & Schreider, 1949; Poudel et al., 2010). It is sometimes accompanied by head nodding.

Flat tracking – Flat tracking occurs when the participant stops responding for an extended period while the target diverges away. Flat tracking can be detected by inspecting both target and response positions in the x and y directions. The response speed approaches zero and tracking error increases (see Figure 3-9).

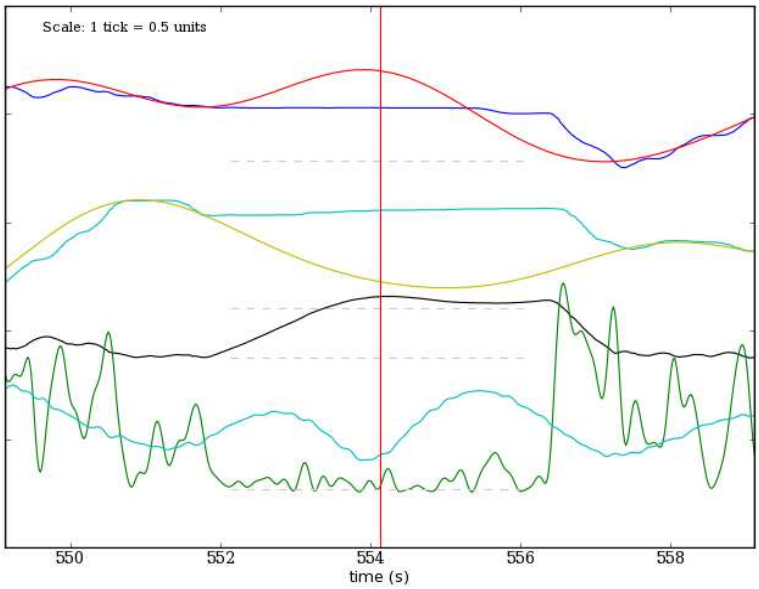

Figure 3-9 Example of flat tracking as displayed by SyncPlayer. The top two lines show the x-axes of the target track (smooth line) and the response (flat line). The next two lines are the y-axes. Partial eye closure occurred at 551.7 s coincidental with the beginning of a flat response. Full eye closure occurred at 552.7 s. Eyes began to open at 555.6 s and were fully opened 300 ms later at 555.9. This was immediately followed by a sacade to the target. Motor response began at 556.4 s.

Incoherent tracking – Incoherent tracking occurs when the response disc moves away from the target for an extended period of time (Figure 3-10). Incoherent tracking can be detected by inspecting target and response positions in both x and y directions. During incoherent tracking, tracking error increases and the response speed will often show substantial differences from the required speed.

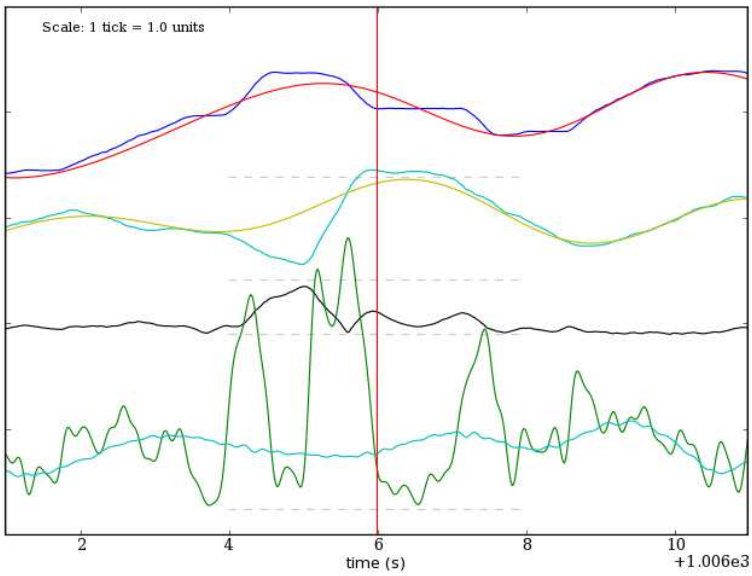

Figure 3-10 An example of incoherent tracking as displayed by SyncPlayer. There is significant divergence of the response position from the target in the x-axis, tracking error is increasing and the response speed is less that needed.

Lapse – A lapse is a complete transient loss of sensory-motor responsiveness.

Poor tracking – Poor tracking occurs when the response disk is only poorly but not incoherently following the target disk resulting is a substantial tracking error. Poor tracking was able to be identified by inspecting both target and response positions in the x and y directions.

Significance Level and p-values

The significance level applied to statistical tests was $\alpha = .05$, which is typically used in social sciences (Coolican, 2005; Moran, 2003).

With respect to multiple comparisons, there is an increased risk of making a type I error unless a correction is applied to the *p* value. Frequently in social science studies, the Bonferroni correction has been employed. However, several recent papers have criticized the Bonferroni correction as being too severe (Columb & Sagadi, 2006; Moran, 2003), because it increases the risk of committing a type II error. Benjamini and Hochberg (1995) proposed a methodology to avoid this criticism by controlling the expected proportion of errors among the rejected hypotheses which they called the false discovery rate (FDR). Accordingly, where multiple comparisons are made in this study, an FDR corrected *p* value was used (Benjamini & Hochberg, 1995; Columb & Sagadi, 2006).

Measures

Five measures were analysed in this study. They are shown in Table 3-5, along with their source – i.e. the task that produced them – and application.

Table 3-5 Measures, and their source.

	Measure	Task Source	Application
Primary	1) Microsleep count	Tracking and dual tasks	To test if task differences impact microsleep frequency
	2) Attention lapse count	PVT and dual tasks	To test if task differences impact attention lapse frequency
Secondary	3) Microsleep duration[1]	Tracking and dual tasks	To test if either task differences or microsleep frequency impact microsleep duration
	4) Tracking error	Tracking and dual tasks	To test task differences and to determine if motor skills reflect microsleep frequency
	5) Reaction time	PVT and dual tasks	To test task differences and to determine if motor skills reflect the frequency of attention lapses

[1] We were unable to analyse this measure because there was only 3 matched samples, which was too few for a meaningful statistic.

Statistical test.

Table 3-6 lists the statistical tests used in this study.

Table 3-6 Research questions, measures and statistical tests.

Research question	Measures	Statistical test used
Do task differences affect rates of microsleeps and attention lapses?	Counts of microsleeps and attention lapses per participant for each task.	Wilcoxon paired-sample signed-rank test.
What effect does time-on-task have on the frequency of attention lapses and Microsleeps?	Average counts of attention lapses or microsleeps per participant, per task, per 5 or 10 min block.	Friedman's ANOVA with multiple comparisons tested using FDR corrected Wilcoxon test.
What is the effect of the task and time interaction on attention lapses	Counts of attention lapses per participant per five minute block	Aligned rank transform test.
What effects do task, and time have on tracking error and reaction times?	Tracking errors and reaction times per participant, per task, per 5-min. block.	Matched-pairs t-test. MANOVA. Multiple comparisons were tested using ANOVA with FDR corrections applied to the p-values.
What correlations exist between tasks?	Average counts of microsleeps and attention lapses.	Spearman's ranked order correlation.
	Average tracking errors and reaction times.	Pearson's product-moment correlation.

General non-parametric factor analysis tests such as the Kruskal-Wallis and Friedman tests can only handle one factor of *N* levels and cannot be used to examine interaction effects (Leys & Schumann, 2010; Sawilowski, 1990; Wobbrock, Findlater, Gergle, & Higgins, 2011). Accordingly, the aligned rank transform test was required.

3.5 Results

The research questions dealt with in this section are listed in the previous chapter in Table 3-6, and the individual data and summary statistics can be seen in Table 3-7. However, before could proceed with those, we needed to correct the reaction times to account for differences in tasks demands between the PVT task and dual task (see section 0).

The mean difference using the fastest 10 % of reaction times for each participant from both the dual and PVT tasks, was 34 ms. Sustained attention lapses in the dual task were identified by subtracting the 34 ms from the raw dual task reaction times and applying the standard threshold of 500 ms to the corrected times. Raw reaction times were used to identify sustained attention lapses in the PVT task.

As it was expected that the impact of attention demands on reaction times would be least at the beginning of the task, the correction was applied over the first 300 s and the results from the corrected dual task

compared with the PVT task. Provided there was no significant difference, this should validate the correction. The average corrected mean reaction time across the first 300 s of the dual task was 310.6 ms with a standard deviation of 42.5 ms. This was not significantly different ($t_{22} = 1.4$, $p = .18$) from the mean PVT task reaction time for the same period (297.3, SD = 47.6). However, uncorrected, the two means (i.e., 344.6 vs 297.3 ms) were different ($t_{22} = 4.6$, $p < .001$).

This suggests the correction was successful in allowing for task requirement differences. Nonetheless, we sought further validation of the correction by counting and comparing attention lapses using the corrected reaction time. The count of attention lapses during the first 300 s of the dual task using the correction had a median of 0 and a range of 0 to 7 (cf. before correction; median 1, range 0–12). The median number of lapses from the first 300 s of the PVT task was also 0 with a range 0–5. The difference in counts was not statistically different (Wilcoxon z = 0.49, $p = .62$). This is further confirmation that the correction applied to the dual task was appropriate.

Moreover, a review of task performance immediately prior to and during fast PVT trials from the dual task confirmed that the task at hand did not alter substantially. In particular, tracking performance did not appear to have been sacrificed for the sake of fast reaction times (see Figure 3-11). This screen capture shows two relatively fast reaction times and, typical of most other PVT trials, there is no sign of the tracking component of this task being compromised. This is evident by the accurate tracking. In addition, a MANOVA conducted on tracking performance over time found no significant effect of task on tracking performance.

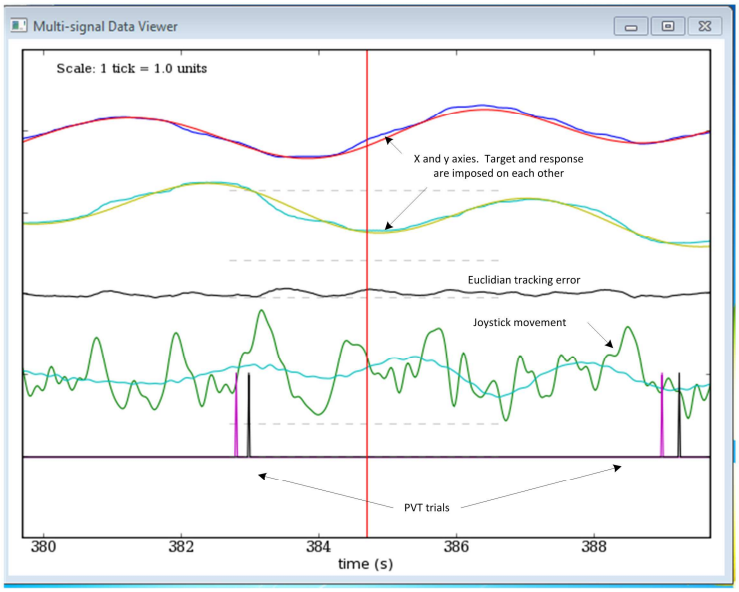

Figure 3-11 Multi-signal output of a participant's performance during the dual task. This figure shows two fast reaction times, 183 ms and 233 ms respectively. The x and y outputs indicate accurate tracking while the joystick output shows that there was joystick movement leading up to and throughout both lapses.

Table 3-7 Individual data and summary statistics for observed microsleeps and attention lapses from the tracking, dual and PVT tasks

	Microsleeps		Attention Lapses	
Participant	Tracking	Dual	PVT	Dual
01	0	0	3	8
02	0	0	2	4
03	0	0	0	6
04	0	0	1	2
05	0	0	76	65
06	0	0	4	13
07	5	0	53	74
08	4	0	12	58
09	0	1	1	15
10	1	1	15	48
11	0	1	6	16
12	0	0	1	1
13	1	0	17	37
14	5	1	2	6
15	18	0	6	24
16	1	0	4	22
17	2	0	1	17
18	14	0	3	7
19	0	0	2	15
20	1	1	9	15
21	0	0	4	19
22	0	0	0	1
23	0	0	2	17
Total	52	5	224	488
Mean	2.26	0.22	9.74	21.22
Median	0	0	3	15
Interquartile range	2	0	8	18

Microsleep counts.

Of the 23 participants included in the analyses (one was removed because of sampling error), 8 participants had more microsleeps on the tracking task than during the dual task, 2 participants had more microsleeps during the dual task, 2 participants had one microsleep on each task, and 11 had no microsleeps at all.

Using only the data from participants who experienced at least one microsleep in either task (n = 12), there was a difference between the tracking versus dual task in the number of microsleeps experienced by each participant (Wilcoxon z = 2.3, p = .022 two-tailed) with more microsleeps during the tracking task than during the dual task (see Table 3-7).

Figure 3-12 shows the effect of time-on-task on microsleep frequency. Although the median count in each of the six 5-min time periods remained at zero for both tasks, an increase in the range occurred over time for the tracking task. A Friedman test for change over time was significant for the tracking task χ^2 (2, N = 23) = 6.72, p = .035 one-tailed) but not significant for the dual task, which remained constant at a count of one throughout the 30-min period.

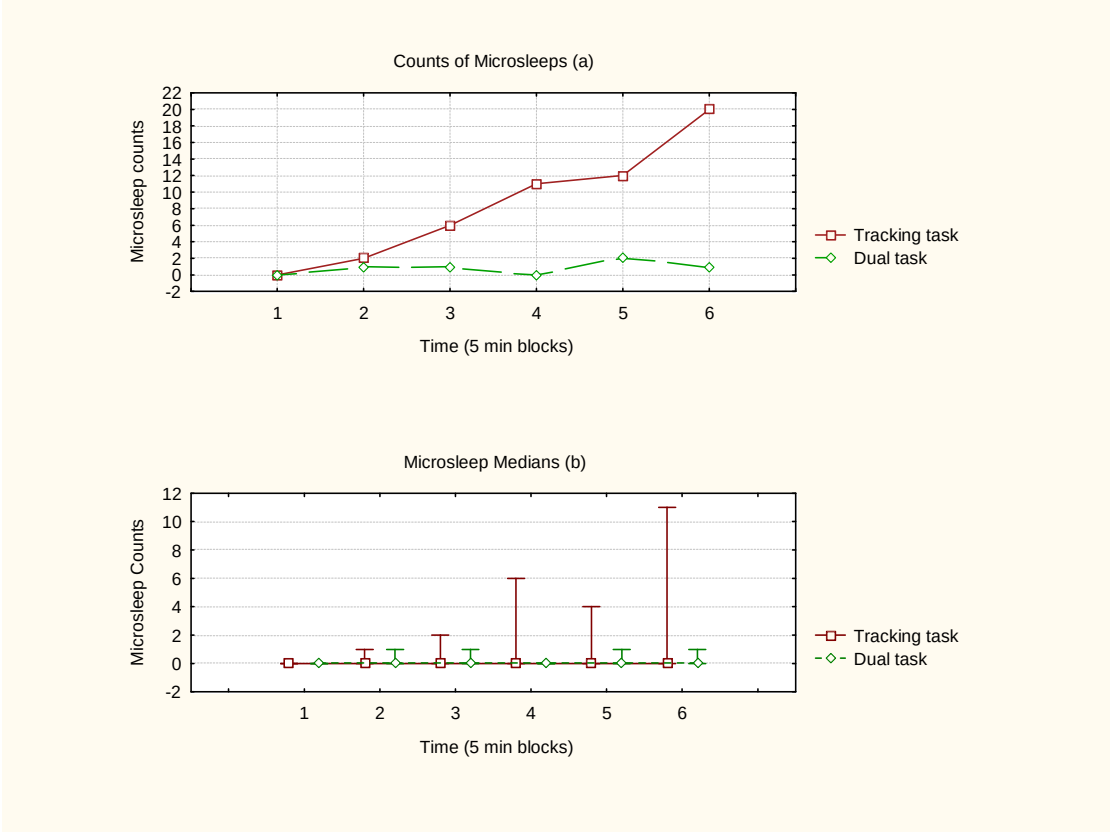

Figure 3-12 The top graph (a) shows the total number of microsleeps in each 5-min period during the tracking and dual tasks. Graph (b) shows the medians while the whiskers indicate the minimum and maximum counts for each 5 min block. Although the median for both tasks does not change over time, the plots show an effect of time for the tracking task but not during the dual task where there were fewer lapses (5 compared to 52).

Consistent with the microsleep frequency data, task appears to also have had an effect on microsleep duration. The average duration of all microsleeps during the tracking task was 1.85 s (SD = 1.30 s). By comparison the average duration of microsleeps during the dual task was 1.33 s (SD = 0.31 s). However, it

was not possible to meaningfully test the intraindividual difference in microsleep duration across the two tasks because of the low number of matched pairs (three).

Sustained Attention Lapse Counts

Using corrected reaction times (i.e., reaction times from the dual task less 34 s to compensate for extra task demands in this condition (refer to section 3.4.3), it was found that 21 participants out of the 23 had more sustained attention lapses in the dual task than in the single PVT task, while one participant had more in the PVT task and one participant had one lapse in each of the two comparative tasks. Furthermore there was a greater number of lapses during the dual task than the single PVT (N = 23, Wilcoxon $z = 3.7$, $p < .001$ two-tailed) (see Table 3-7).

Using Friedman's test to evaluate change over time, the frequency of attention lapses increased significantly across both tasks χ^2 (5, $N = 23$) = 16.33, $p < .006$ for the PVT task; and χ^2 (5, $N = 23$) = 48.69, $p < .001$ for the dual task (see Figure 3-13).

Post-hoc comparisons were made across the six 5-min periods and tested against false-discovery-rate (FDR) corrected *p*-values. An effect was found in the PVT task, mostly across the earlier periods, whereas, the dual task showed differences across all of the 5-min periods (see Table 3-8).

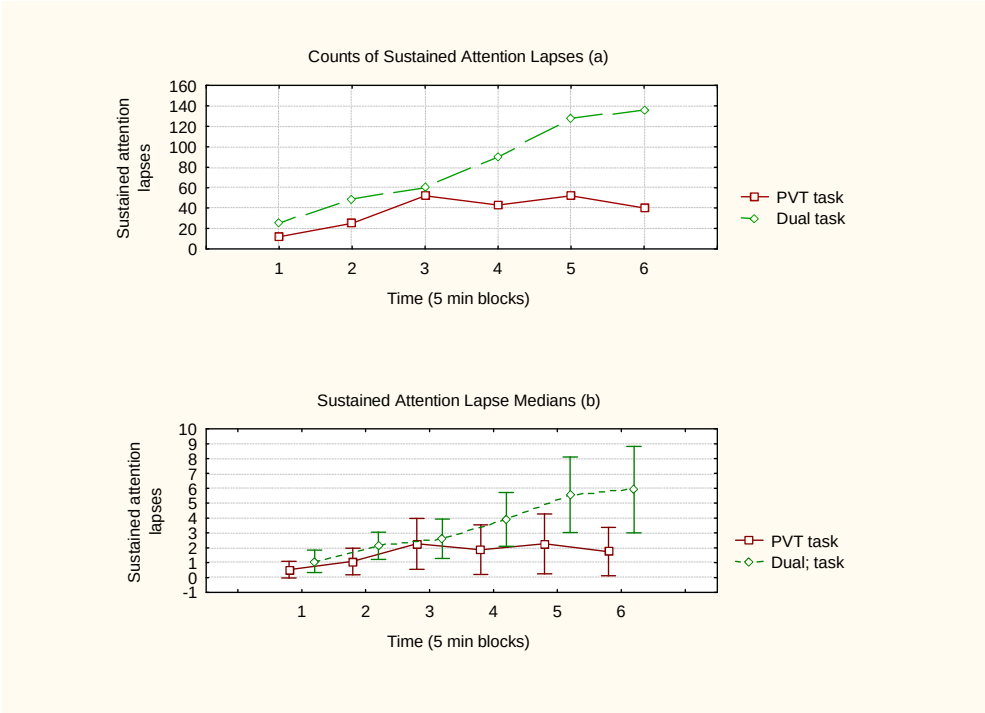

Figure 3-13 The top graph (a) shows the total number of sustained attention lapses in each 5-min period during the PVT and dual tasks using reaction times corrected by subtracting 34 ms to account for differences between tasks due to tasks demands. Graph (b) shows the medians while the whiskers indicate the minimum and maximum counts for each 5 min block. Evident is the effect of time on both tasks which manifests as an increase in counts.

Table 3-8 Post-hoc comparisons of attention lapse counts in each 5-min period during the PVT task (upper) and dual task (lower). *p*-values are FDR-corrected.

PVT task	Periods	2	3	4	5	6
	1	n.s	.009	.015	.019	n.s.
	2		.011	n.s.	.041	n.s.
	3			n.s.	n.s.	n.s.
	4				n.s.	n.s.
	5					n.s.
Dual task	Periods	2	3	4	5	6
	1	.009	.000	.000	.000	.000
	2		n.s.	.005	.003	.003
	3			.013	.004	.002
	4				n.s.	.013
	5					n.s

A time-on-task interaction was also found between counts of sustained attention lapses using a non-parametric 'aligned rank transform test. This test is recommended if the sample size per condition is under 30 and the conditions necessary for a normal distribution are not met (Leys & Schumann, 2010). Sustained attention lapse counts from the dual task increased more rapidly over time than sustained attention lapses during the PVT task $F_{5, 264} = 4.02$, $p = .002$.

Tracking Ability

To determine if task performance was affected by differences between the type of task (tracking and dual task) and to determine what, if any, impact either completion order, time, or interactions between those three variables might have, a multivariate analysis of variance (MANOVA) was conducted. The assumptions required of a MANOVA, that is a sample size in each cell (n = 23 in this study) greater than the number of dependent variables (12), independence, linearity, homogeneity of variance covariance, and normality (Nehlig, 2004; Stafford, 2003), were sufficiently met for the test to be considered appropriate.

Table 3-9 presents the results of the repeated-measures MANOVA. The only significant effect on tracking ability was time. That is, tracking ability deteriorated during the task (Figure 3-14). However, there was no interaction of time on task, which led to the conclusion that the effect of time was not moderated by task.

Table 3-9 Repeated measures MANOVA tests for tracking accuracy.

Effect	Wilks λ	F	Effect df	Error df	P
Task	1.00	0.01	1	21	.920 n.s
Time	0.15	18.60	5	17	.000***
Task*Time	0.74	1.17	5	17	.363 n.s

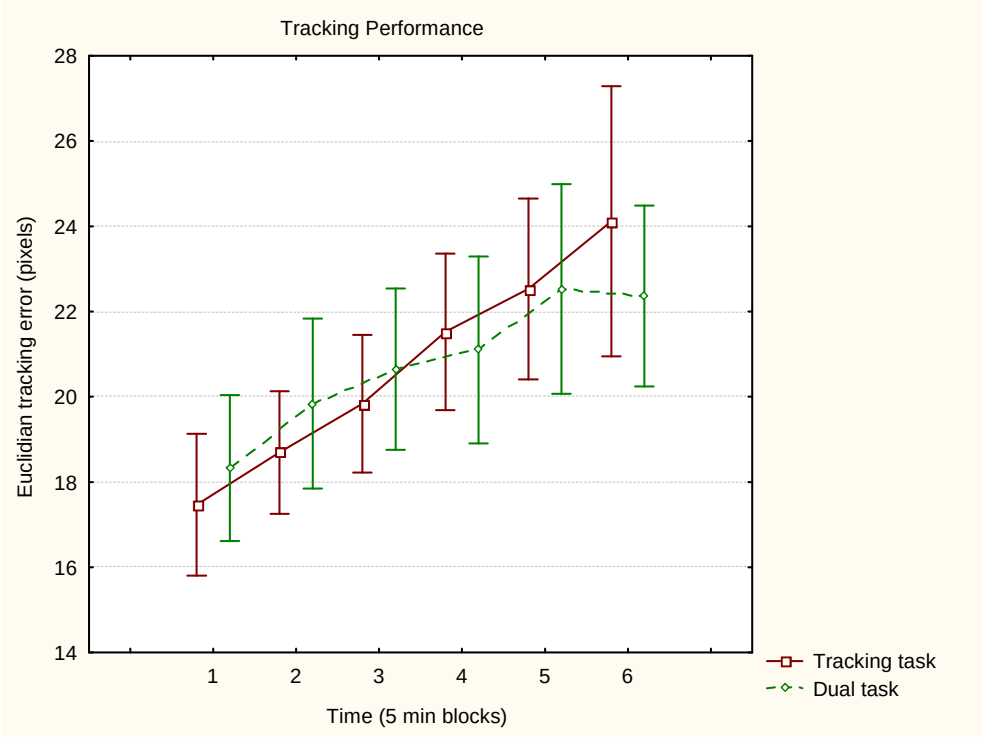

Figure 3-14. This plot shows that tracking error increases with time spent on both tasks. Tracking error in each block is the Euclidian distance between target and response stimulus (measured in pixels) that has been averaged over a 5-min period.

The MANOVA result for the main effect of time was followed up with multivariate ANOVAs to determine if tracking ability was affected by time in both tasks or only in one. The results of the FDR-corrected ANOVA's indicate that time had an effect on both tasks ($F_{5, 105} = 18.98$, $p < .001$; $F_{5, 105} = 57.25$, $p < .001$; for the tracking and dual tasks respectively). This is also consistent with there being no task and time interaction

Table 3-9).

Reaction Times

PVT reaction times were examined for effects of task, and time on task. Sphericity could not be assumed so a repeated-measures MANOVA was considered to be the appropriate test. Again the necessary assumptions for a MANOVA test were met.

Two effects were significant; time and task (Table 3-10).

Table 3-10 Repeated measures MANOVA tests for Reaction Times.

Effect	Wilks λ	F	Effect df	Error df	P
Task	0.18	98.63	1	21	.000 ***
Time	0.23	11.69	5	17	.000 ***
Task*Time	0.57	2.59	5	17	.064 n.s

The effect of task is presented in Figure 3-15, where it can be seen that reaction times in the dual task were on average 65.2 ms or ≈ 19 % longer than those in the PVT task (see Table 0-1 for summary statistics).

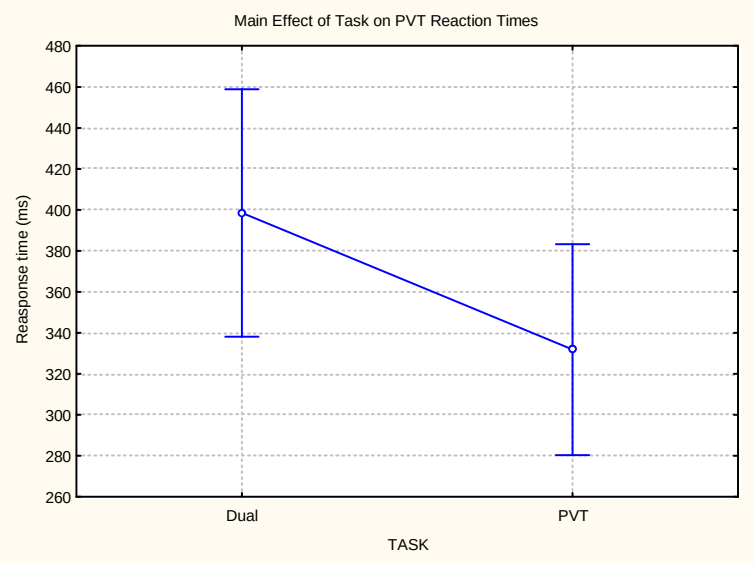

Figure 3-15 This plot shows the effect of task on reaction times. Reaction times are on average more than 60 ms slower during the dual task.

Following on from the main effect of time on PVT reaction times, further analyses using ANOVA were conducted to determine if the effect of time impacted either tasks, or just one of them. Again using FDR corrections for multiple comparisons, the ANOVAs were significant for both the dual task ($F_{5,105} = 25.3$, $p < .001$) and PVT tasks ($F_{5,105} = 7.05$, $p < .001$). The effect time-spent-on-task had on reaction speed is presented in Figure 3-16.

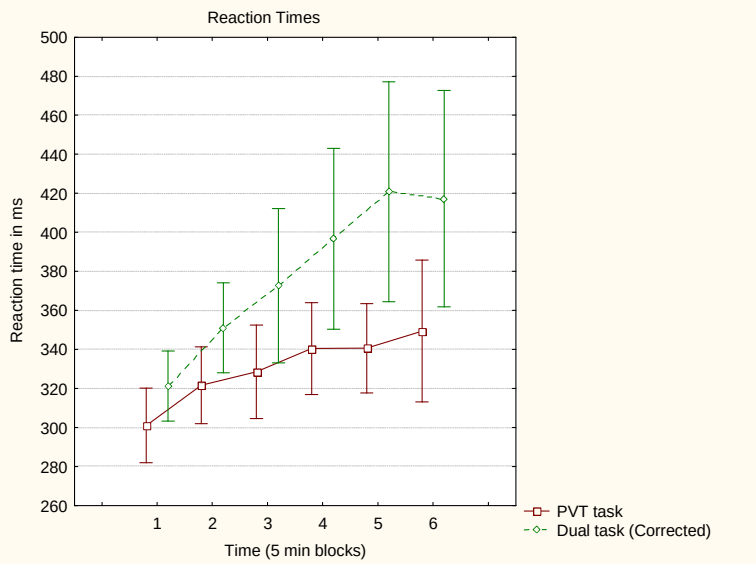

Figure 3-16 Plot showing the effect that time on task had on reaction times. On average, reaction times were 18 % slower at the end of the task than at the beginning

3.5.1 *Correlations between Tasks*

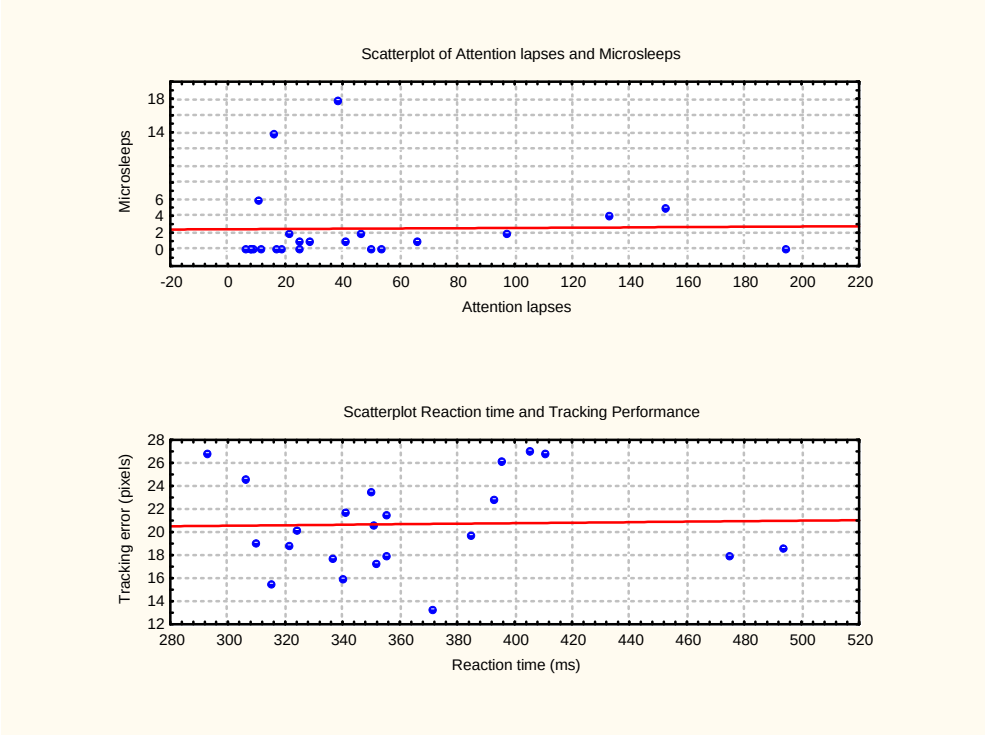

Figure 3-17 A scatterplot of attention lapses and microsleeps per participant and summed from both comparative tasks, is shown in the top plot. The lower plot is of participant's reaction times and tracking error that again were summed from both comparative tasks. There are no significant relationships.

Using Spearman's rank order correlation test, neither microsleeps nor attention lapses were significantly related in the dual task ($r_{s\ 22}$ = .06, p = .80), nor were mean tracking error and mean reaction times ($r_{s\ 22}$ = .03, p = .89). These results indicate that there is no linear relationship between a participant's propensity for microsleeps and attention lapses or between their mean reaction time and mean tracking error. Relationships between these two sets of measures are shown as scatterplots and linear regression lines in Figure 3-17.

Spearman's correlation coefficients were used to determine whether a participant's count of microsleeps in the tracking task correlated with their count of microsleeps in the dual task; and whether attention lapses in the PVT task correlated with attention lapses in the dual task? Scatterplots of these two relationships are presented in Figure 3-18. Microsleeps in the tracking and dual tasks were not correlated ($r_{s\ 22}$ = -.02, p = .93). However, attention lapses in the PVT task were significantly related to those in the dual task ($r_{s\ 22}$ = .81, p < .001).

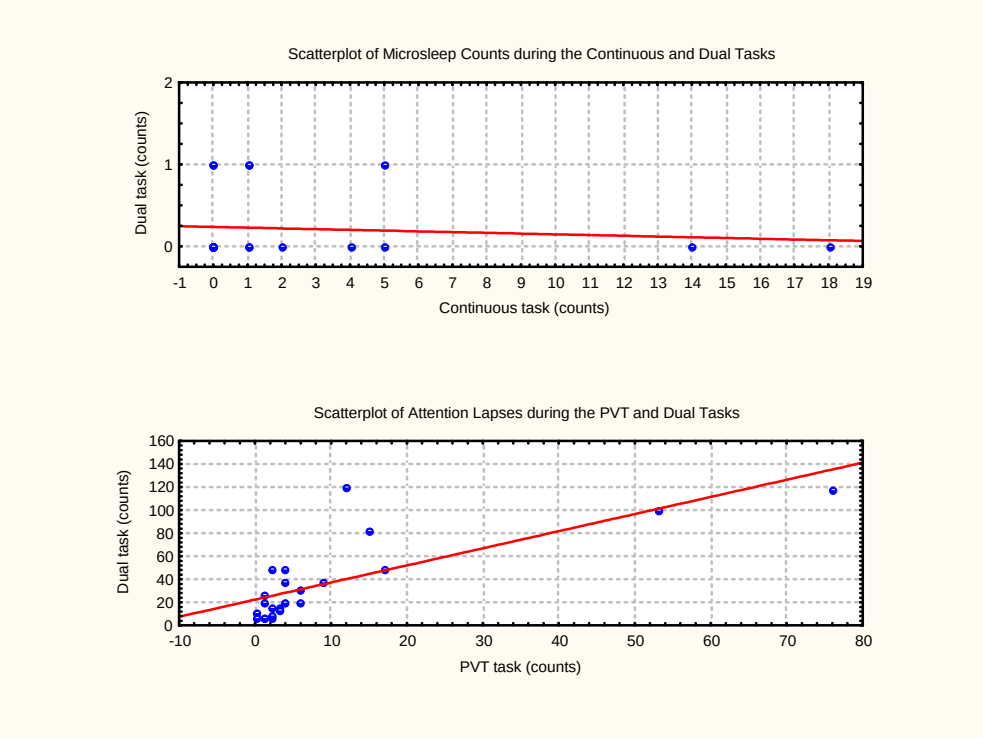

Figure 3-18 Scatterplots of microsleep and attention lapse counts from their respective comparative tasks. The top graph plots microsleeps in the tracking task against the same participant's count in the dual task. Most participants did not microsleep in either task, particularly the dual task and this is reflected in the weak relationship. The bottom graph plots attention lapses from the PVT task and dual task where a stronger relationship is evident.

While it was appropriate to use Spearman's rank order correlation coefficients on the count data because of non-normality (Wood, 1986), Pearson's product-moment correlation coefficient could be used to assess the relationships between tracking error and reaction time data. Similar questions to those above were asked: Is

there a relationship with respect to reaction times between the PVT and the dual tasks; and with respect to tracking error, between the tracking and the dual tasks?

Graphical representations of these two relationships are shown in the following scatterplots (see Figure 3-19.

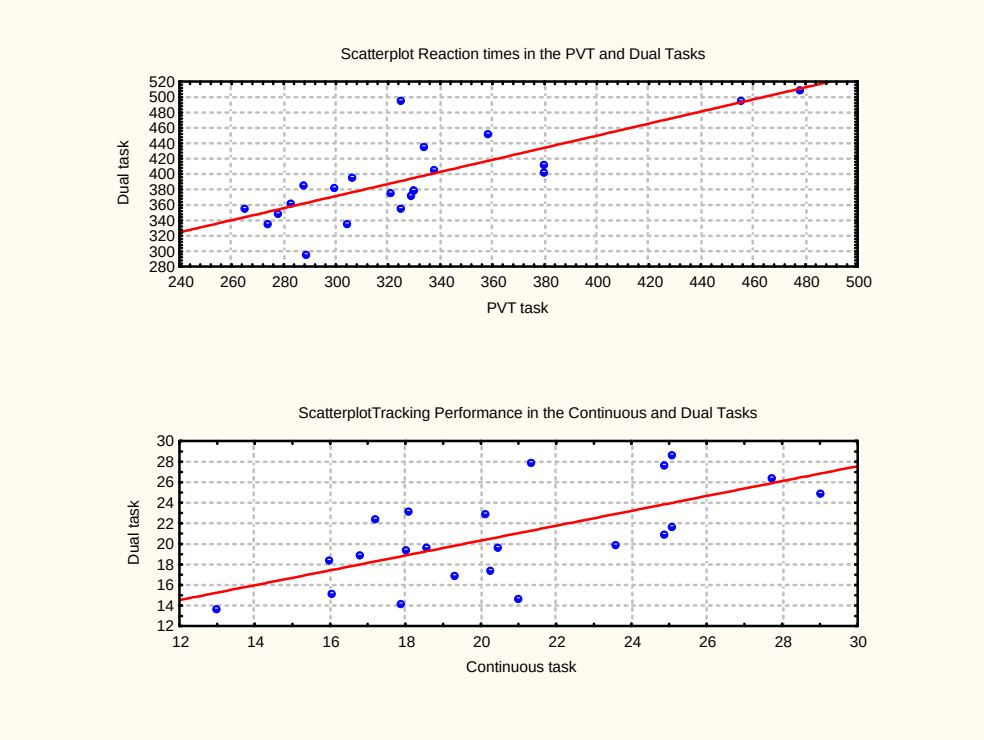

Figure 3-19 Scatterplot of reaction times in the PVT and dual task is shown in the top plot. The lower plot is a scatterplot of tracking errors from the tracking and dual tasks. The relationships are quite strong, r = .77 for the reaction time and r = .66 for tracking errors.

Tracking errors made during the tracking task were related to tracking errors during the dual task (r_{22} = .66, p < .001), as were reaction times during the PVT and dual tasks (r_{22} = .77, p < .001). These are relatively strong relationships that provide compelling evidence that, in general 50% of a participant's performance in one task, as measured by either tracking error or reaction times, is a reflection of their performance in the other comparative task. These results are not surprising as the correlated pairs are from the same person and reflect their intraindividual source.

The within subject correlation between tracking error and reaction times during the course of the dual task was calculated by comparing a participant's mean tracking error within a 5-min period with their mean reaction time in the same period (r_{136} = .76, p < .01). The result was a positive relationship indicating that faster reaction times were associated with higher tracking accuracy. Furthermore, on average, 58% of a participant's reaction time to a PVT trial could be accounted for by the accuracy of their tracking.

3.6 Discussion of Results

3.6.1 *Key Findings from the Research Questions*

The first research question asked was: Do task differences affect rates of sustained attention lapses and/or microsleeps? Both sustained attention lapses and microsleep rates were found to be affected by task differences. A participant is more likely to experience a sustained attention lapse when undertaking the dual task then when undertaking the stand-alone PVT task. Conversely, a participant is more likely to experience a microsleep when undertaking the stand-alone tracking task than when undertaking the cognitively more demanding dual task.

The next was: Does time-on-task have an effect on the frequency of microsleeps and sustained attention lapses? It was found there was a time-on-task-effect. Microsleeps increased with time-on-task during the tracking task but not during the dual task. Attention lapses in the dual task increased in the second 5-min block, levelled off in the third 5-min block before increasing over the fifth and sixth blocks. In the PVT task, attention lapses increased in the third block, levelled off during the forth block before decreasing in the fifth block, however, there was an overall increase between the first and fifth blocks. In addition, sustained attention lapses increased at a greater rate over time during the more cognitively demanding dual task.

The third question was: What effect does task and time have on tracking error and reaction times? While there was no main effect of task on tracking error, both tracking and dual tasks showed a main effect of time-on-task on tracking error. However, the PVT task and dual task both showed main effects of task and time-on-task on reaction times. In addition, the time-on-task-effect appears to be stronger on the dual task than the PVT, albeit the result was not significant.

The last question was: What correlations existed between the tasks? Sustained attention lapses were not correlated with microsleeps and reaction times were not correlated with tracking error. A participant's count of sustained attention lapses was correlated across tasks, as were reaction times. However, a participant's microsleep count in the tracking task was not correlated with their count in the dual task, albeit that tracking error was correlated across tasks.

3.6.2 *Study into Lapses of Responsiveness*

Most studies into lapses of responsiveness have used either a continuous task, or a discrete task, and few have used a combination of both. Yet, if we are to gain a complete understanding of the etiology of lapses in the real world and avoid erroneous conclusions, it is important that an investigation is made of the effect of task complexity on lapses of responsiveness. Accordingly, the primary aim of this study was to confirm that differences in task complexity, differentially impact on an individual's propensity to lapse. More specifically, we sought to compare measures of attention lapses and measures of microsleeps using separately and combined, continuous and discrete tasks that would alter task complexity (Liu & Li, 2012).

This study has demonstrated that an individual is more likely to experience a lapse of sustained attention during a 30-min dual task, a task that because of its greater task complexity, places a higher cognitive demand on a participant than does the 30-min PVT task (Wickens, 2008). This is despite reaction times in the dual task needing to be 34 ms longer (to counter task differences) than the minimum 500 ms threshold used to identify a sustained attention lapse in the PVT task . Nonetheless, more participants had a sustained attention lapse in the dual task than those that did in the PVT task and furthermore, the number of sustained attention lapses in the dual task was more than twice as many as from the PVT task. However this difference was not evident during the first 5-min block and sustained attention lapse counts only began to differentiate during the second 5-min block but they did so at a greater rate in the dual task.

This study also demonstrated that fewer participants had microsleeps in the more complex dual task than they did in the simpler tracking task. Furthermore, the number of microsleeps experienced by those that did, was lower in the dual task.

We attribute these results to changes in task complexity arising from the combination of the PVT and tracking task to form the dual task because the other variables – task assignments, order, and intraindividual differences, including sleep propensity factors – were either balanced or equivalent. More specifically, we can discount changes to the task assignments making up the dual task and the other two stand-alone tasks. This is because the assignment in the PVT task i.e., the discrete visuomotor vigilance assignment had the same task parameters when used in the dual task. Similarly, the continuous visuomotor tracking assignment that was used in the dual task was identical to that used in the tracking task. However, when undertaken concurrently, the two assignments interact in a complex manner and it is the impact of this interaction on behaviour that is suggested as the reason for the different scores.

We can also discount an order effect. If left uncontrolled, the order which tasks are completed could have had an impact on fatigue, motivation, and skill levels; all of which are known to affect performance (for example, Åkerstedt, 2009; Lynn, 1966; Matthews et al., 2002a; Thayer, 1987). In particular, the design of the tasks that consisted of a 30-s block repeated 60 times to make up the 30 min trial could provide an opportunity to develop tracking and response skills learning, which if left unchecked may have unduly influenced the results; although it is unlikely that practice would have a direct impact on attention lapses (Flehmig, Steinborn, Langner, Scholz, & Westhoff, 2007; Strobach, Liepelt, Pashler, Frensch, & Schubert, 2013). Nonetheless, a practice effect could indirectly influence sustained attention and microsleeping if left unchecked. In this study the order in which the three tasks were completed was balanced. We also confirmed that there were no order significant order effects.

With respect to individual differences, we were given some leeway with sample homogeneity because we were interested only in within (intraindividual) differences. Nonetheless, because we wanted to be able to extrapolate the results to the healthy general population, participants were screened for sleep deprivation, and health issues that would unduly impact the results. Moreover, they were asked to refrain from coffee

and other stimulants earlier in the day of the test session. Furthermore, to control for intraindividual factors, the three tasks were completed under consistent conditions during the one session. The testing occurred in the same location under the same ambient conditions and post-lunch. Holding each session to these tight constraints reduced environmental and intraindividual differences that may have otherwise confounded the results.

Other experimental design factors that needed to be controlled were the extraneous factors expected when two tasks are combined. This was particularly important with respect to sustained attention lapses because attention lapses from the dual task, as defined by reaction times, would be compared directly with the reaction times from the PVT task. Even if we were not to expect there to be attentional differences we should still expect there to be different reaction times because of what we called task demands (see section 3.4.3).

Task demands are the additional demands that accrued in the dual task because of changes in the physiological mechanics of responding to a PVT stimulus during a tracking assignment (i.e., making a response to a stimulus while purposefully moving the joystick as opposed to making a response without the requirement to move the joystick), and because of non-attention related cognitive differences such as asymmetry of effort. This is the case where a participant may prioritize one assignment over the other because of individual preferences – i.e., they attend more to the tracking assignment at the expense of the PVT assignment. This confounding effect of task demand needed to be corrected in order for the study to make valid comparisons.

That there was no difference in sustained attention lapses over the first 5 mins suggests the correction that was applied (34 ms) was appropriate. Importantly, this correction applied in this study did not fully explain the observed difference in sustained attention lapse counts.

The variable that was not controlled across tasks was complexity. This varied according to task. Adding the tracking assignment to the vigilance requirement in the dual task increased the complexity of this task and varied the level of exogenous stimulation between tasks. Therefore, we credit the change in counts of lapses to changes in task complexity.

The results also confirmed that, with one possible exception, an individual is more prone to attention lapses and also to microsleeps with time on task. The exception was microsleeping during the dual task where the low count of microsleeps limited the power of statistical testing. However, generally, as time progressed so did the propensity to experience sustained attention lapses and microsleeps. Similarly, an individual's tracking errors and reaction times also increased over time.

These differences over time were not due to changes in task complexity over the duration of the task; as the tracking task was comprised of 30-s identical blocks. Similarly, the task parameters for the PVT did not change over the 30 min. The shape and presentation of the stimulus remained the same and the inter-stimulus interval remained within 2–9 s over the course of the task.

Although it is suggested that the differences in counts of both sustained attention lapses and microsleeps are the result of changes to task complexity brought about by combining two tasks, it is not suggested that the effects of the combination impact each participant to the same extent or same manner. If it did, then we ought to see a significant correlation, either positive or negative between a change in a participant's count of attention lapses with their change in microsleeps; a correlation that should also be reflected between other markers of task performance – i.e., changes in reaction times with changes in tracking errors from the comparative tasks. However, such correlations were absent. Therefore, we cannot conclude that the change in task complexity had a global effect on an individual's propensity for sustained attention lapses or microsleeps. Rather the impact differentially affected each participant's propensity. For a few, attention lapses and microsleeps both went up in the dual task but for the rest attention lapses went up but microsleeps went down or stayed the same. With respect to reaction times and tracking performance, all participants experienced an increase in reaction times in the dual task but for approximately half there was an improvement in tracking performance and for the other half a decrease. These results are consistent with the premise that microsleeps and attention lapses are reasonably well separated; behaviourally at least.

3.6.3 *Sustained Attention Lapses*

Having concluded that more sustained attention lapses occurred because of changes to task complexity, how does this contribute to the debate surrounding theories of sustained attention?

Robertson and O' Connell (2010, p. 85) stated in support of the mindlessness theory, "… that performance could be significantly improved, at least temporarily, by increasing arousal through exogenous mechanisms." However in this study, we found that contrary to their expectations, adding the tracking assignment to the PVT task – a mechanism that because of its moving stimuli and response would increase exogenous support during the dual task – induced more lapses. In addition, combining the PVT task and the tracking task, such that they must be performed simultaneously, is considered to increase the mental workload and consequentially the resource demand (Wickens, 2008). Therefore we conclude that the increased number of attention lapses in the dual task over the PVT task was due to increased resource demands, which aligns with the resource depletion theory.

Further support for this conclusion is provided by the increase in sustained attention lapses that occurred over time, and that occurred at a greater rate in the dual task than in the PVT task. In other words the task that had the higher cognitive demand had the greatest decline in sustained attention performance over time. Furthermore, we were unable to differentiate between the counts of lapses in the first five minutes of the PVT and dual tasks, which is consistent with the resource depletion theory as is the interaction between time and task. Although, by itself, this time-on-task-effect is not sufficient to differentiate the mindlessness theory from the resource depletion theory, a time-on-task-effect is an important indicator of resource depletion (Helton & Russell, 2012; Langner & Eickhoff, 2012).

However, despite the results providing strong support for the depletion theory, we are unable to dismiss the mindlessness theory. Although the task most likely to induce mindlessness, the PVT task, was associated with the least number of sustained attention lapses, sustained attention lapses still occurred during that task, albeit at a lower rate than the dual task. Because we have no way of knowing if these sustained attention lapses were due to mindlessness or to depleted resources or to some other reason, we investigated whether mindlessness could exert its influence through an intermediary effect.

The tracking assignment provides greater exogenous support for attention than does the PVT assignment by virtue of its continuous nature and feedback. Accordingly, there is a reduced need for endogenous input to maintain performance on the tracking assignment compared to the PVT assignment. Moreover, it could be argued that when the two tasks are combined this asymmetry is at times selectively maintained (Matthews et al., 2010). In fact it would not be unreasonable to argue that during the dual task the increased lapse rate was due to attention being captured by the tracking assignment to the extent that attendance to the PVT assignment was neglected, or in other words, because of selective attention. The finding that there was no main effect for task on tracking performance does not weaken this proposition.

Could such conjecture align with the mindlessness theory? The mindlessness theory posits that attention is captured and held by other stimuli or task-unrelated thoughts because of low levels of exogenous stimulation provided by the vigil assignment. Nonetheless, it would seem oxymoronic that mindlessness could be selective. Rather, it is more likely that any difficulty dividing attention was due to increased demands placed on higher-level control areas required to control lower-level sensory areas (McMains & Somers, 2004) and to the limited processing capacity of the high-level control systems (Driver, 2001; Nebel et al., 2005) or to the extra working memory load required by attending to dual tasks (Ernst, Palmer, & Boynton, 2012; Santangelo & Macaluso, 2013).

Regardless, neither the mindlessness theory nor divided attention could adequately explain the increase in sustained attention lapses observed over time. While the above arguments might have held if the number of sustained attention lapses remained the same or decreased over time, it is difficult to accept that the tracking assignment would be such an engaging task that it would increasingly capture attention as time on task increased. It is much more likely that as time on task increased so did monotony and boredom (Hill & Perkins, 1985; Smith, 1981), and therefore a different explanation is needed.

Accordingly, we propose a resource-based explanation for these results. First, the increased count of sustained attention lapses found in the dual task would suggest that fewer resources were available for that assignment in the dual task than during the stand alone PVT task. Therefore the balance must have been allocated to the tracking task. In other words, at least some of the resources used in sustained attention are common with the tracking task. Furthermore, because tracking performance did not change between tasks but the PVT assignment results did, the tracking assignment must have received sufficient resources not to have been affected; however, that allocation must have occurred at the expense of the vigilance task.

In summary, the positive association between the more demanding task and the highest sustained attention lapse count that increased over time provided substantive support for the resource depletion theory, whereas the prediction based on the mindlessness theory that the highest count of sustained attention lapses ought to occur in the more monotonous task was not supported. This conclusion is directed by the view that while it may be possible during a dual task for the tracking assignment to capture attention to the detriment of the PVT assignment, the results in this study (the increased count of sustained attention lapses and the time on task effect in the dual task) indicate that was unlikely to be the case.

Mindlessness: Is it the Result of Resource Depletion?

During the inter-stimulus period of a vigilance assignment, both the mindlessness theory and the resource depletion theory accede that endogenous effort is required in the absence of exogenous support if performance during the vigil is to be maintained. One theory suggests this demand can lead to resource depletion, while the other suggests that a mindlessness state occurs which permits the intrusion of TUTs. It may be entirely possible that in some instances, the intrusion of TUTs is not the result of mindlessness per se, but is the result of resource depletion.

Although this proposition that mindlessness might be the result of resource depletion is not helped by the absence of a clear consensus of opinion on exactly what resources are depleted, there is a body of evidence to support it. For example, it is possible that activation of the default mode network (DMN), which is sometimes cited in support of the mindlessness theory (Bonnelle et al., 2011; Esterman et al., 2012; Hasenkamp et al., 2012), is an attempt to compensate for resource shortfalls (Leech, Kamourieh, Beckmann, & Sharp, 2011). Furthermore, Gilbert, Dumontheil, Simons, Frith, and Burgess (2007) cautioned against the presumption that activity of the default mode network indicated only mindlessness. They cited evidence that suggests DMN activity also predicts watchfulness. Furthermore, McVay and Kane (2009) have suggested that TUTs are mediated by resource demands. They tested 244 young adults (aged 18–35 yrs) on a SART during which they probed for TUTs and compared the results against working memory capacity. Participants with a lower working memory capacity experienced more TUTs during a resource demanding primary task than did higher working memory capacity participants. They provisionally concluded that TUTs represented an executive-control failure to maintain goal directed behaviour. In their view, TUTs, which according to Bar (2007) are automatically and continuously generated as part of an organisms thought stream, are kept at bay during resource-demanding tasks by executive-control processes. This proposition by McVay converges with the work of Langner et al. (2010) who proposed a theoretical cost benefit model of sustained attention in which self-regulatory control mediated between the resource demand theory and the mindlessness theory (see also Langner & Eickhoff, 2012). They suggested that self-regulation – a construct akin to Stuss et al.'s supervisory system (1995) that is needed to sustained attention (Rueda, Posner, & Rothbart, 2004) – was a limited resource that became depleted over time and depletion of this resource resulted in mindlessness. Similarly, Fennis and Janssen (2010) pointed to self-regulation as a limited resource. Lastly, but not exhaustively, Langer (2012)

concluded that not only does mindlessness occur through repetition, and habituation, but also occurs because of limited cognitive processing.

Sustained attention could represent different constructs as indicated by the number of different definitions used in the literature. First, a vigilance decrement that occurs over a long period of time (measured in hours) cannot be assumed to be the same type of decrement as one that occurs after a much shorter time (measured in minutes). Secondly, attention is a heterogeneous process with many ways to attend to a stimulus using both bottom-up and top-down inputs. Thirdly, the neural basis of sustained attention has multiple structures that in some instances overlap with the ascending arousal systems (Posner & Petersen, 1990). Furthermore Chee et al. (2008) concluded that brain activity differed during sleep-deprived lapses of attention from that following a normal night's sleep. They found differences in the frontoparietal regions responsible for mediating cognitive control, extrastriate visual cortex involved in visual discrimination, and in the thalamus, which has a major role in arousal as well as modulating visual processing. Lastly, unless resource depletion occurs very early in the piece, then the resource depletion theory does not adequately explain the early presence of sustained attention lapses, where it could be presumed that attentional resources are still fresh. For example, in this study, 6 participants had a sustained attention lapse in the first 5 min of the PVT task (median number of lapses for those who lapsed =1; range 1–6) and 10 participants lapsed in the first 5 min of the dual task (median = 2; range 1–7) albeit that these inter-task differences were not significant. It would not be unreasonable to suggest that these early lapses are different from later lapses i.e., early lapses are the result, perhaps, of response errors while later lapses result from reduced stimulus activity (Weissman et al., 2006). Nonetheless, Helton et al. (2007) found that sustained attention lapses, that they creditied to resource depletion, occurred within 2 min of a sustained attention task (see also Temple et al., 2000). The task, which involved witholding a response to two non-critical signals (probability of presentation = 40 % each) and responding to a critical signal (presentation probability = 20%) was correlated with increased blood velocity and oxygenation levels .

While these definitions are not always clearly separated, it does seem evident that a vigilance task, where a subject must wait and recognise a signal before responding is fundamentally different to a task that requires the maintenance of a correct response such as pouring milk into a request cup of black coffee. Such divergences point away from the premise that there is a unitary cause of sustained attention lapses just as there is no unitary cause for any complex system failure.

Under the supervisory-attention-system framework of Norman and Shallice (1986), appropriate goal directed schemata must be maintained for the successful completion of both tasks. However, a breakdown in goal directed schemata could occur for a number of reasons. For example, a fatigue mediated breakdown in a schema that requires response levels to be maintained close to thresholds limits, as is required in vigilance assignments, could result in perceptual sensitivity decrements, whereas the displacement by one schemata by another is likely to lead to an everyday attention lapse. When those possibilities are considered in light of the various constructs for sustained attention, it should not be assumed, that the absent

mindedness of Carriere et al. (2008); Cheyne et al. (2006) and Robertson et al. (1997) is the same construct used by Helton and Warm (2008); Warm et al. (1996) and Mackworth (1948) in their discussions on the vigilance decrement.

Summary of Sustained Attention

This study found that the resource depletion theory of sustained attention lapses provided the only viable explanation for the decrement in vigilance performance observed in the dual task. The dual task is a more demanding task than the tracking task yet contrary to what the mindlessness theory would predict, more attention lapses occurred in it than in the tracking task. This study has also made a contribution to the type of resources that are depleted. We have found that at least some of the resources, used to maintain sustained attention, are also used during the tracking assignment, which is a continuous visuomotor task. We have also tentatively suggested that mindlessness, which has not been falsified by this study, could be the result of resource depletion. We cited a limited selection of the extant literature that suggests an alternative resource based causation pathway of mindlessness to that which has been traditionally proposed; but we stress that much more work would be required before this conjecture is much more than a point of interest. Finally, we have suggested the possibility that the current debate between resource theorists and mindless/boredom theorists could be better informed by a greater clarity on what is meant by sustained attention.

3.6.4 **Microsleeps**

Microsleeps during the dual task were almost eliminated, whereas microsleeps during the tracking task were significantly higher than the dual task. For the same reasons put forward in the discussion on sustained attention, this difference is not considered to be the result of changes to the component tasks, order of tasks and individual differences; and, as was the case with attention lapses, the reason for the difference is attributed to interactions from combining the two component tasks and the impact those interactions have on the causation pathways of microsleeps.

The primary difference between the dual task and the tracking task in this study was in the level of exogenous support provided by each task. While the tracking task required substantial volition for maximal performance, the nature of the task meant there was a continuous stream of exogenous stimuli available to direct the schema used in the mediation of response plans. This stream of exogenous stimulation was provided via the instant feedback available to the participant who was able at any time to see where they had placed the response cursor in relation to the target. Furthermore, the required joystick response very closely resembled the stimulus movement. When the target moved to the top right hand corner of the screen, the joystick was also required to be moved into the same quadrant. As the target increased in speed, so too must the joystick movement. This close relationship between response and stimuli can be measured by what Greenwald (2003) has referred to as ideomotor compatibility. A high level of compatibility could mean that a response is selected without accessing limited-capacity processes and is in line with the work of

Stuss et al. (1995) who suggested well-learned processes can be managed by schemata. However, these schemata can become deactivated unless maintained by a supervisory system.

It also converges with Manly et al. (1999) who theorized that a continuous stream of exogenous stimulation would reduce the need for internal (endogenous) attention to be directed to the response selection. In other words, the more exogenous support offered to the relevant schema, the harder it will be for the operator to maintain subjectively-willed supervisory control over their task. As a consequence, task disengagement is more likely to occur and energetic arousal levels could decline.

On the other hand, the need to remain vigilant for a randomly-presented onset stimulus during the PVT assignment means that participants must exercise subjectively-willed supervisory control, particularly during the inter-stimulus period. The response required by the PVT assignment has what Greenwald would call, low ideomotor compatibility. Therefore according to this theory, the PVT response would place a demand on cognitive processes. Furthermore, the random inter-stimulus interval would preclude an automatic response, which cannot occur until after the stimulus has been presented, albeit the response from that point forward is relatively straightforward. It is this wilful process that generates task engagement and maintains energetic arousal levels (Levine et al., 2006; Matthews et al., 2002a).

Poudel and colleagues (Poudel et al., In Press) proposed that microsleeps were due to complex interactions involving attention, arousal, and sleep/wake processes. The results in this study point to arousal that, according to Matthews et al. (2010), is linked to task engagement. Accordingly, the evident reduced number of microsleeps found in the dual task compared to the tracking task is attributed to reduced arousal mediated by task differences in exogenous and endogenous stimulation.

That arousal should be implicated in our propensity to microsleep is not surprising given recent research that microsleep propensity increases following sleep deprivation (Innes et al., In press) or that a fMRI study by Poudel and colleagues (in press) associated microsleeps with decreased neural activity in the arousal-related brain regions including the thalamus, midbrain, and posterior cingulate cortex, but associated with increased activity in the frontoparietal, insular, parahippocampal, and temporo-occipital cortices. It is also not surprising that other possible microsleeps (i.e., EEG-defined microsleeps) have also been widely linked to sleep and hence to arousal (Chee et al., 2008; Harrison & Horne, 1996). According to the widely accepted two-process model of sleep proposed by Borbély (1982), normal sleep occurs when the arousal system is switched off through the influence of circadian and homeostatic processes operating through a self-regulating feedback system that is commonly compared to a flip-flop switch (Saper et al., 2010). This type of switch normally ensures that sleep is a stable process resulting in consolidated periods of sleep and wakefulness. However, microsleeps are far from stable periods of consolidated sleep. For some people, they are very frequent: up to 225 per hour with an event duration range 1.1–6.3 s and mean of 1.85 s (Innes et al., In press; Poudel et al., In Press). These findings are not consistent with the normal stability of consolidated sleep. On the face of this, it might suggest that microsleeps are outside of the mechanics

associated with normal sleep. However, Fuller et al. (2006) provide a possible explanation in noting that "either/or" switches possess the property of undesirable sudden state transitions. Where this occurs, smaller than normal perturbations could trigger transitions into and out of the sleep state.

It is asserted by this study that 'abnormal' perturbations probably occur in the arousal system which are not primarily related to homeostatic or circadian sleep drives albeit that both of those drives play important roles in the sleep process (Borbély, 1982). The microsleeps in this study were found in non-sleep deprived participants as was also the case in Peiris et al. (2006a) and (Poudel et al., In Press). All participants included in this study had reported in their questionnaire response usual sleep patterns leading up to the experimental trials. Furthermore, the trials took place in the afternoon during a period they would be expected to normally be awake. Therefore, it can be assumed that the homeostatic drive for sleep was not excessive due to sleep deprivation. We can also assume that the circadian drive was not abnormally high despite the trials occurring in the postprandial period where the circadian drive is partially elevated because none of the participant's had experienced time zone shifts in the month prior to the study. Therefore it was suggested that the sleep- promoting effect of these two drives would not be sufficient to overcome the wake-promoting effects of normal daytime arousal levels. Importantly though, the study design counterbalanced the order in which the three tasks were completed and controlled the homeostatic and circadian drive. However, arousal levels were varied across the tracking and dual tasks.

According to the two-process model for sleep, should there be a sufficient fall in normal arousal levels a state transition from wakefulness to sleep could occur. Empirical support for this proposition was provided by Poudel et al. (In Press) who found BOLD activity in the regions associated with the arousal system decreased immediately prior to a microsleep episode and that the decrease in activity was related to microsleep duration with a smaller decrease correlated with briefer microsleep durations.

However, the transition from wake to consolidated sleep is not instantaneous and in humans can take minutes to resolve (Saper et al., 2010). It is suggested that, during the transition period before sleep consolidates, arousal levels are increased, possibly mediated by brain regions associated with consequences, and that this increased activity triggers a reversal halting or even reversing the transition into consolidated sleep. Support for this premise comes from Poudel et al. (In Press) and Chee et al. (2008), who reported that widespread bilateral activity increased in the frontoparietal cortices during a lapse and that this increase in activity may "… constitute a mechanism for ending microsleeps and restoring responsiveness" (Poudel et al., In Press p.10) .

3.6.5 *Resource Depletion and Microsleeps*

This research found that microsleep counts increased as time on task increased. Furthermore, the count of microsleeps from the first 5 min of each comparative task were equivalent at zero for both tasks and were also similar over the following five minutes (2 for tracking task; 1 for dual task) before the rate of microsleeps from the tracking task separated at a greater rate from those occurring during the dual task (see

Figure 3-12). Although these findings are not by themselves sufficient to unequivocally support a resource depletion theory, they are indicative of resource depletion that according to Matthews and Davies (1998) has been used, in a metaphorically sense, to explain performance decrements found in a number of studies.

However, if microsleeps are the result of depleted resources, then the depleted resources cannot be those resources used directly in visuomotor processing (i.e., tracking a continuous target) as visuomotor processing was also a condition in the dual task. Furthermore, not only did the dual task involve a continuous visuomotor assignment, it also involved a discrete visuomotor assignment. Arguably, the visuomotor processing demands were greater in the dual task, yet microsleeps were almost absent in that condition. Therefore, if the performance decrement suggested by the increased microsleep count were to be ascribed to resource depletion, we need to look elsewhere for the putative depleted resources.

The additional discrete visuomotor assignment in the dual task differentiated the dual task from the tracking task in an important way. It added a vigil assignment to the task that, unlike the continuous tracking assignment, is not exogenously supported. Therefore, in order to perform well in this task, the participant must maintain a greater level of task engagement in the dual task, than in the tracking task. This greater level of task engagement is necessary to provide the endogenous support for sustained attention. Furthermore, performance feedback provided after each PVT trial during the dual task, which must be wilfully processed, would therefore, serve to keep the participant engaged in the task. Whereas, it is argued that the continuous feedback from the tracking task would be less salient because it is continually processed automatically.

The link between task engagement and resource depletion could, for example, be provided by Kahneman's resource theory (1973). This theory posits that flexible but limited resources, which are set by arousal levels, are subjected to an allocation policy. If insufficient resources are allocated to a task they become depleted. When arousal levels are optimal, the maximum amount of resource becomes available. Furthermore, when arousal levels are too low, or too high, then resource levels become suboptimal (see also Matthews & Davies, 1998).

Given its idiomatic characteristics, in comparison to the dual task, the tracking task can be considered a monotonous task (Poudel, 2010). It is not unreasonable to suggest that during monotonous tasks, arousal levels are reduced (Matthews & Davies, 1998). Such a proposition is supported by Poudel et al. (In Press) who found that low cortical arousal during a continuous tracking task was associated with higher microsleep propensity.

Accordingly, the possibility that reduced arousal levels limit the resources necessary to maintain task engagement is considered. That depleted resources affect task engagement is not new (Matthews et al., 2010). Matthews et al. proposed that task engagement functions as a marker for resource availability; albeit that task-focused coping and effort possibly mediate this effect. Nonetheless, their proposal suggests that as resource availability decreases, so too does task engagement. Furthermore, they proposed that task

engagement is bound to energetic arousal and that the link between task engagement and information processing is bi-directional (i.e., task engagement affects information processing and information processing affects task engagement). As they said, (p. 226), "…performance failure and task monotony may perpetuate a vicious cycle of ever decreasing engagement and use of avoidance coping." When viewed together, this suggests a pathway where reduced arousal levels limit the resources necessary for task engagement that as a consequence is decreased. Lowered task engagement, reduces arousal levels leading to a further decrease in task engagement. It may be possible that over time, arousal spirals downwards thereby increasing microsleep propensity.

In this scenario, the depleted resources are those resources necessary for the maintenance of mindful task engagement and that a possible direct cause of microsleeps is mindlessness mediated by task engagement. That task engagement is itself mediated by motivation and effort is also informative as it helps explain why, anecdotally at least, people supposedly microsleep during dangerous tasks such as driving. However to move beyond conjecture, further research would be required to empirically establish that low levels of task engagement do indeed result in microsleeps. Although this study found higher microsleeps occurred in a putative lower arousing task (the tracking task), measures of task engagement were not collected and any link between task engagement and microsleeps remains conjecture.

3.6.6 *Conclusion*

This study set out to investigate the impact of task complexity on a person's propensity to lapse. We had argued that tasks requiring little endogenous support would, because of reduced arousal, be more prone to microsleeps than tasks that required higher levels of endogenous support. Conversely, we had also argued that tasks that required high levels of endogenous effort, such as the discrete task, would, according to the resource depletion theory, be more prone to attention lapses than tasks where reliance on endogenous support was reduced. As expected, there were more microsleeps when participants completed the tracking task on its own than during the dual task. Furthermore, and again as expected, there were more sustained attention lapses experienced by participants completing the dual task compared to the PVT task on its own. These results suggest that when the endogenous demands are relatively high we experience more sustained attention lapses. Conversely, when the endogenous demands are low and the task complexity is simpler we experience more microsleeps. This is not unlike a computer that slows down when overloaded and goes to 'sleep' to save power when under-loaded.

The study also sought to separate two prominent theories of sustained attention lapses – the mindlessness theory and the resource depletion theory. The finding that more sustained attention lapses occurred in the more complex dual task compared to the simpler PVT task provided support for the resource depletion theory, which posits that vigilance consumes limited resources and that deficits sometimes occur. Furthermore, the task that was most likely to induce mindlessness because of monotony (tracking task), had

the least number of sustained attention lapses, which was contrary to that predicted by the mindlessness theory.

Nonetheless, despite this study being able to convincingly confirm the presence of resource depletion, it was not able to dismiss the possibility of some lapses being due to mindlessness and even the possibility of mindless lapses being due to resource depletion. To do so would require us to demonstrate that no sustained attention lapses could occur because of mindlessness. We could not do that. We were only able to demonstrate that, in this particular paradigm, sustained attention lapses were most likely the result of resource depletion.

Although we were not able to empirically link mindlessness to sustained attention lapses, we have tentatively suggested that mindlessness, mediated by task engagement, may influence microsleep propensity but not sustained attention lapses. We have outlined a possible theoretical link between resource-depleted task engagement and arousal levels based on the work of Kahneman (1973) and Matthews et al. (2010), and consequentially microsleeps.

3.6.7 *Discussion of Analysis Issues*

Outlier.

Outliers can be a legitimate source of important information and as such they should be retained and allowed to influence our conclusions (Hamilton, 1990). However, they can also have a deleterious effect on statistical analyses. They can skew the distribution, inflate the variance, reduce the power of the tests and bias the results (Osborne & Overbay, 2004; Yarkoni & Braver, 2010). Therefore careful consideration needed to be given to the treatment of an outlier identified in this study.

The outlier was one participant who had many more microsleeps than did other participants. That participant had 83 microsleep episodes in the dual task and 65 episodes in the tracking task. The next highest counts were 1 and 18 respectively.

Osborne and Overbay (2004) recommend that if the outliers are from a sampling error, or are the result of a standardization failure (i.e., research methodology) they should be removed. According to Yarkoni and Bravera (2010), this approach is common in psychology, but it comes with a caution: where the sample size is small and the power is already low removing an outlier may be unwise. Moreover, they say that dropping outliers arbitrarily can lead to an inadvertent bias.

To help with this type of quandary, Hamilton (1990) proposed three tests. The first test was to determine if the outliers would exert undue influence over the conclusion. The second test was to determine why the outlying cases were so extreme – i.e., what made them unusual and were the reasons relevant to the studies goal. The third test was to determine if the outliers were just the long tail of a skewed distribution, in which case Hamilton recommended retaining the outliers but changing the shape of the distribution. Changing the shape of the distribution was an option also suggested by Neter, Wasserman, and Whitmore (1997).

However, Dunlap, Chen and Greer (1994) warned against the indiscriminate transformation of data. They pointed out that because of theoretical and logical considerations it is possible some data sets can only be understood in their original form. They also point out that the changed data cannot be interpreted in terms of the unchanged data unless it is inversely transformed back. Furthermore, there are limitations if it is intended to compare studies. However, of more importance to this study is that when the sample size is small, as it is in this study, the transformation used to reduce the skew may not be the same as that used to transform the population being represented. Although they do not oppose transformation, they urge caution.

In conclusion, a decision was made to remove the outlier. This was based on Hamilton's three tests. First, the outlier would have undue influence over the results from a parametric analysis because of the distance it lies from the centre of both distributions. Secondly, a retrospective review of the participant indicated they did not meet sleep history requirements (i.e., the participant regularly went to bed at 01:30 am and rose before 08:00am) and because of that he/she constituted a sampling error as they did not belong to the population being investigated. Thirdly, the outlier was clearly not simply on the long tail of a skewed distribution. Although, increasing the sample size can reduce the influence of outliers; in this study that strategy was not a viable option due to the cost of time and money. Finally, the possibility of an undiagnosed sleep disorder cannot be dismissed in this participant.

Over Dispersion

This study included a high count of zeros in the microsleep count data. For example, 12 out of 23 participants did not microsleep in the tracking task and 18 participants did not microsleep in the dual task. How these zeros arose and how best to treat them required careful thought if incorrect or inefficient statistical inferences were to be avoided (Martin et al., 2005). An example is the question of distinguishing between true and false zeros. This is an important consideration wherever it is intended to compare populations, because both groups need to belong to the same class. In order to make a valid comparison between lapse counts it is important that we are comparing the results of those who belong to the class of 'those who lapse'. Because of interpersonal differences it cannot be assumed that everyone will microsleep. For example, the sleepiness trait as measured by the Epworth Sleepiness Scale is thought to impact both the circadian and homeostatic sleep drives (Bakotic & Radosevic-Vidacek, 2012), furthermore, personality is also known to impact arousal and other brain responses to cognitive demands (Colquhoun & Edwards, 1975; Curtindale et al., 2007; Matthews et al., 2010).

A difficulty with matched pairs where the count is zero is to know if the results are from someone who otherwise would have microsleeps or are the results from someone who would not microsleep even when sleep restricted. For example, Innes et al. (In press) had one of 16 participants who was sleep restricted but did not microsleep. Fortunately it only takes one lapse by a participant to falsify the premise that they belong to the 'do not lapse' class. Accordingly, equal matched pairs that are non-zero provide

unambiguous evidence that the comparison is valid. However, when a participant's count is zero for both tasks it is not possible to falsify the premise that the participant does indeed lapse. This means it is impossible to determine if the lapse rates are equivalent or that a differentiation has been masked because, for instance, the necessary threshold for lapsing was not reached. In other words, unless a participant lapses in at least one of the comparative tasks it is impossible to infer that a particular type of task would promote within that participant more or less lapses or indeed if the lapse rate would remain the same. Their inclusion does nothing to answer the hypotheses but does confound the results particularly if the algorithm is dependent on a valid N.

Where possible, this problem was solved by using the Wilcoxon paired-sample signed-rank test as this non-parametric statistical procedure discards equal ranks, irrespective of whether they are non-zero or not. Elsewhere, matched pairs with a value of zero were discounted.

Chapter 4. Concluding Summary and Outlook

4.1 Main Findings

The principal objective of this study was to investigate the impact of cognitive workload on two types of lapses: sustained attention lapses and microsleeps. We did that by comparing the frequency of sustained attention lapses during two tasks that differed in their cognitive workloads. By comparing the results of relatively high and low cognitive workloads we were be able to contribute to the debate surrounding the two competing theories of attention lapses. Specifically, we were able to demonstrate that more sustained attention lapses occurred during a more demanding task. This finding contributed to the debate between the two theories by adding support to the resource theory of lapsing. It also made an important contribution by demonstrating that, contrary to what would be expected by the mindlessness theory, adding to a task increases propensity for sustained attention lapse. However, although the outcome was not that predicted by the mindlessness theory on its own that, by itself, is not sufficient to falsify the theory.

Secondly, by comparing the frequency of microsleeps during two contrasting tasks, we were able to empirically establish a relationship between microsleep propensity and task complexity. We created two levels of task complexity by combining the tracking task with the dual task. This increase in task complexity almost totally eradicated the propensity for microsleeps. This is an important finding as it points towards possible solutions to a growing problem, particularly in increasingly automated industries. For example, maintaining arousal levels in new generation air traffic control systems by leaving sufficient complexity in the task to ensure task engagement. Although this is contrary to the conclusion made in respect of sustained attention lapses, it fits with Yerkes Dodson's law where too little arousal causes a decrement in performance as does too much arousal (Broadhurst, 1957).

4.2 Critique

An objective of this study was to investigate tasks and their impact on lapses of sustained attention. Although we were able to accurately measure sustained attention lapses and microsleeps, objective measures of task engagement and subjective measures of monotony and boredom were not collected. Although these are subjective measurements, they can be informative nonetheless. Had this information been collected, it could have added more depth to the discussion.

It was also disappointing that the number of microsleeps that would occur and the number of participants who would microsleep was over estimated. Other studies of behavioural microsleeps have demonstrated much higher numbers of microsleeps and a higher proportion of participants who had microsleeps (Innes et

al., In press; Peiris et al., 2006b; Poudel et al., In Press). It is worth noting that in two of those studies, the participants lay supine in a very noisy environment of the fMRI machine. The small number of participants reduced our sample size and meant that we were unable to compare the duration of microsleeps over time between the two tasks because of the small number of matched pairs.

In this study we were not unable to measure sustained attention lapses in the tracking task, nor were we able to measure microsleeps in the PVT task in a manner that would allow valid comparisons to be made across tasks. With respect to measuring sustained attention lapses during the tracking task, we had no clear means of measuring reaction times in a way that would allow a valid comparison to reaction times from the PVT trial. With respect to measuring microsleeps during the PVT, we were unable to distinguish non-responses during the inter stimulus period without a fundamental change to the task.

4.3 Future Research

This study set out to investigate what impact task complexity would have on lapse propensity. While this was an important question to ask it was just one of a number of questions that require answers. Task performance is not only affected by complexity but also by our subjective attitudes to the task. Factors such as monotony, boredom, and task engagement are factors that are likely to influence propensity for lapses. Although much work has been done concerning those factors and sustained attention lapses, little work on the impact of those factors on microsleeps has been done. Although this study looked into the impact two different tasks had on microsleep propensity, and by virtue of contrasting two different tasks most likely contrasted different levels of monotony, boredom and task engagement, it did not measure those factors. Therefore, a natural next step would be to measure those factors so that the differences in microsleep propensity found in this study could be better understood.

Furthermore we conjectured a theoretical pathway linking resource-mediated task engagement with arousal levels and subsequently microsleep propensity. However to move beyond conjecture, further research is needed despite the finding that the distribution of microsleeps was consistent with a depleted resource over time. In particular, an empirical link between subjective task engagement and microsleeping would be important.

Similarly, future research could utilize physiological measures such as fMRI, NIRS, and EEG to contrast microsleeps and sustained attention lapses. Such measures have proven to be useful in studies of attention (e.g., Lim & Dinges, 2008; Stevenson et al., 2011; Wingen, Kuypers, van de Ven, Formisano, & Ramaekers, 2008) where they have been used as a measure of cognitive demand, to isolate regions of cortical activity and identify sleep states and arousal levels. They have also proven to be useful in microsleep research where they have been used to map brain activity during the course of a microsleep and the time immediately surrounding microsleeps (e.g., Harrison & Horne, 1996; Poudel et al., In Press).

This study also set out to provide more clarity about the prominent theories on sustained attention. Although it provided evidence in support of the resource depletion theory, it was not able to definitively dismiss the mindlessness theory. However, it has raised the question: Is there more than one underlying cause of attention lapses or do the two theories attempt to describe different constructs, albeit they both call their construct 'sustained attention'? The possibility has also been raised that mindlessness could, at least in part, be a consequence of resource depletion. Although Grier et al. (2003) contrasted measures of workload using the NASA TLX with the Dundee stress state questionnaire, it does not appear evident that the NASA TLX has been contrasted against measures of mindfulness/mindlessness such as Langer's mindfulness/mindlessness scale or the mindful attention or awareness scale (Höfling, Moosbrugger, Schermelleh-Engel, & Heidenreich, 2011). Nor does it appear that measures of mindfulness/mindlessness have been used in studies of sustained attention. (Haigh, Moore, Kashdan, & Fresco, 2011; Langer, 1989). Therefore a useful research question would be: Can mindfulness be fatigued and as a consequence result in sustained attention lapses?

Finally, microsleeps were identified by visually rating behavioural information incorporating tracking metrics and video recordings of a participant's eyes. However, the rating process is not straightforward and is very time consuming. Every event has to be judged and rated based on its context. Was a stopped-response intended, perhaps as a strategy to re-establish accuracy, or was it an unintended lapse? Was an eye lid closure a sign of drowsiness, or a normal blink, albeit a very slow blink? If future studies wish to make comparisons between studies, then it would be useful to complete an inter-rater reliability study. The significance of such a study would be greater confidence by readers of the study in its ecological validity.

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Appendix A Consent Form

Behavioural Microsleeps and Attention Lapses during Continuous Tracking, Psychomotor Vigilance, and Combined Tasks

I have read and understand the Research Information Sheet (dated 23 March 2010) and I volunteer to participate in this research study. I have had the opportunity to discuss this study and I am satisfied with the answers I have been given. I have had the opportunity to use the support of family or friends to help me understand this study and I have been given sufficient time to consider whether to take part.

I voluntarily choose to participate. However, I understand that my consent does not take away any legal rights I might otherwise have in the case of negligence or other legal fault of anyone who is involved in this study. Furthermore I understand that should I withdraw, that withdrawal will not affect my future health care, academic progress, or employment prospects.

I understand that my participation in this study is confidential and that no material which could identify me will be used in any reports on this study.

I know who to contact if I have any side effects to the study or if I have any questions about the study.

I understand the compensation provisions for this study.

I wish to receive a lay person synopsis of this study. I am aware that a significant delay may occur between data collection and publication of the results. **YES / NO**

I consent to my face, head and shoulders being videoed taped during the trial **YES / NO**

I consent to the information gathered about me being stored for use in future lapse research studies, subject to ethical approval being given by a New Zealand accredited ethics committee **YES / NO**

I consent to the non-identifiable data collected in this study being stored for use in future research studies, subject to ethical approval being given by a New Zealand accredited ethics committee **YES / NO**

I understand and accept that this research is not offering diagnostic advice and that no clinical advice will be offered. **YES / NO**

I, _____ hereby consent to take part in this study.

Signature _____ Date _____

Project explained by _____

Signature _____ Date _____

Primary researcher: Russ Buckley, BA (Hons), Masters Student
Department of Psychology
University of Canterbury
C/ Van der Veer Institute for Parkinson's and Brain Research
Phone: 03 378 6096

Principal investigator: Associate Professor Richard Jones
Department of Medical Physics and Bioengineering
Canterbury District Health Board
C/ Van der Veer Institute for Parkinson's and Brain Research
Ph. 03 378 6077

Note

1. A copy of the consent form to be retained by participant and a copy to be placed on file
2. This study has received ethical approval from the Upper South A Ethics Committee.

Appendix B Questionnaire

CONFIDENTIAL

Behavioural Microsleeps and Attention Lapses during Continuous Tracking, Psychomotor Vigilance, and Combined Tasks.

This study has been approved by the Upper South B Regional Ethics Committee

QUESTIONNAIRE

Please read each question carefully and answer ALL of the questions in this booklet.

It is important that you understand that all of the information you provide for this study is strictly confidential.

If you have any questions or concerns please ask the Primary researcher.

Primary researcher:

Russ Buckley Phone: 027 221 0893 Email: russell.buckley@vanderveer.org.nz

Principal Investigator:

Prof Richard Jones Phone: 03 378 6077 Email: richard.jones@vanderveer.org.nz

GENERAL

Name …….

What sex are you? *(Please tick)* 1☐ **Male** 2☐ **Female**

What is your date of birth? ..... /..... /.....

(day) (month) (year)

The following is the 2001 census form question about ethnicity. This data is collected for statistical purposes only, to assist with planning future studies.

Have you traveled overseas in the last four weeks? 1☐ Yes 0☐No

If yes, where did you travel? ……

Please list the average amount of caffeine you consume per day:

(For example, how many cups of tea/coffee, cans of caffeinated soft drink and chocolate bars would you have in one day)

.....

SMOKING

Do you describe yourself as a:

1☐ Regular smoker
(I smoke one or more cigarettes per day)

2☐ Occasional smoker
(I do not smoke every day)

3☐ Ex-smoker
(I used to smoke but not any more)

4☐ Non-smoker
(I have never smoked regularly)

ALCOHOL

How often do you drink alcohol?

0☐ Never 1☐ Less than once per week 2☐ Once or twice per week 3☐ Once every 2 days 4☐ Daily

On a typical drinking occasion, how many drinks do you have? (One drink equals a glass of beer, a glass of wine or a nip of spirits).

0☐ None 1☐ Fewer than 2 drinks 2☐ 2-4 drinks 3☐ 5-6 drinks 4☐ More than 6 drinks

GENERAL HEALTH

Have you had any serious accidents, head injuries, or concussion? 1☐ Yes 0☐No

Are you currently on any medication?

(prescription or over the counter) 1☐ Yes 0☐No

If so, what medication? .....……

Are you currently suffering from any neurological disorders?

(e.g. migraines, epilepsy) 1☐ Yes 0☐No

If yes, what disorders? .....……

Have you had any head or brain surgery? 1☐ Yes 0☐No

Are you currently suffering from any mental illness? 1☐ Yes 0☐No

If so, what illness(es)? .....……

Are you currently suffering from repetitive strain injury on your wrist, shouler or elbow?

(e.g. due to excessive mouse and keyboard use) 1☐ Yes 0☐No

SLEEP

Have you ever been diagnosed with a sleeping problem? 1☐ Yes 0☐No

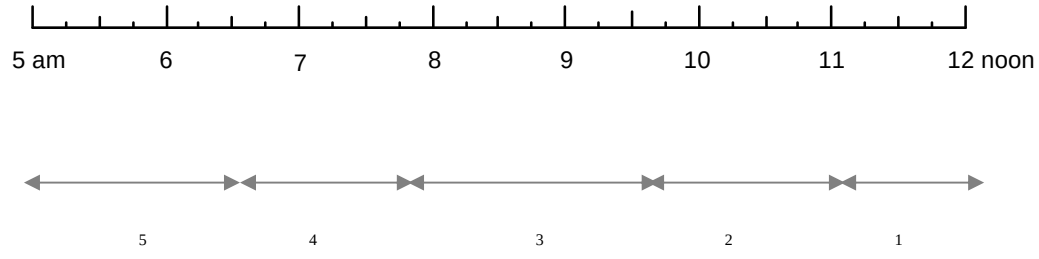
If yes, please describe

.....

.....

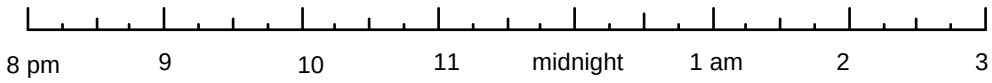
What time of day do you get up?

Please put a cross at the time closest to your best time.



What time of day do you go to bed?

Please put a cross at the time closest to your best time.



How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? This refers to your usual way of life in recent times.

PLEASE TICK ONE BOX PER LINE

Would never doze	No chance	Slight chance	Moderate chance	High Chance
Sitting and reading	0☐	1☐	2☐	3☐
Watching TV	0☐	1☐	2☐	3☐
Sitting inactive in a public place (e.g. theatre, meeting)	0☐	1☐	2☐	3☐
As a passenger in a car for an hour without a break	0☐	1☐	2☐	3☐
Lying down in the afternoon when circumstances permit	0☐	1☐	2☐	3☐
Sitting and talking to someone	0☐	1☐	2☐	3☐
Sitting quietly after a lunch without alcohol	0☐	1☐	2☐	3☐
In a car, while stopped for a few minutes in traffic	0☐	1☐	2☐	3☐

SLEEP HABITS:

The following questions relate to your usual sleep habits during the past month *only*. Your answers should indicate the most accurate reply for the *majority* of days and nights in the past month. **Please answer all questions.**

1. During the past month, when have you usually gone to bed at night?

USUAL BED TIME _____

2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?

NUMBER OF MINUTES _____

3. During the past month, when have you usually gotten up in the morning?

USUAL GETTING UP TIME _____

4. During the past month, how many hours of *actual sleep* did you get at night? (this may be different than the number of hours you spend in bed.)

HOURS OF SLEEP PER NIGHT _____

For the remaining questions, check the one best response. **Please answer *all* questions**.

5. During the past month, how often have you had trouble sleeping because you……

a) Cannot get to sleep within 30 minutes

Not during the past month ☐ Less than once a week ☐ Once or twice a week ☐ Three or more times a week ☐

b) Wake up in the middle of the night or early morning

Not during the past month ☐ | Less than once a week ☐ | Once or twice a week ☐ | Three or more times a week ☐

c) Have to get up to use the bathroom

Not during the past month ☐ | Less than once a week ☐ | Once or twice a week ☐ | Three or more times a week ☐

d) Cannot breathe comfortably

Not during the past month ☐ | Less than once a week ☐ | Once or twice a week ☐ | Three or more times a week ☐

e) Cough or snore loudly

Not during the past month ☐ | Less than once a week ☐ | Once or twice a week ☐ | Three or more times a week ☐

f) Feel too cold

Not during the past month ☐ | Less than once a week ☐ | Once or twice a week ☐ | Three or more times a week ☐

g) Feel too hot

Not during the past month ☐ | Less than once a week ☐ | Once or twice a week ☐ | Three or more times a week ☐

h) Had bad dreams

Not during the past month ☐ | Less than once a week ☐ | Once or twice a week ☐ | Three or more times a week ☐

i) Have pain

Not during the past month ☐ | Less than once a week ☐ | Once or twice a week ☐ | Three or more times a week ☐

j) Other reason(s), please describe _____

_____

_____

How often during the past month have you had trouble sleeping because of this?

Not during the past month ☐ | Less than once a week ☐ | Once or twice a week ☐ | Three or more times a week ☐

6. During the past month, how would you rate your sleep quality overall?

Very good ☐ | Fairly good ☐ | Fairly bad ☐ | Very bad ☐

7. During the past month, how often have taken medicine (prescribed or "over the counter") to help you sleep?

Not during the past month ☐	Less than once a week ☐	Once or twice a week ☐	Three or more times a week ☐

8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

Not during the past month ☐	Less than once a week ☐	Once or twice a week ☐	Three or more times a week ☐

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?

No problem at all ☐	Only a very slight problem ☐	Somewhat of a big problem ☐	A very big problem ☐

Please answer the following questions in order.

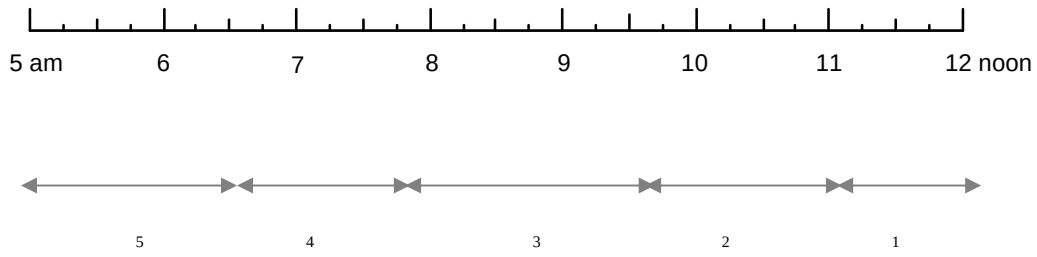
Do not go back and check or change your answers.

What time of day do you like to sleep?

Imagine that you are completely free to plan your day. Think only about what feels best for you.

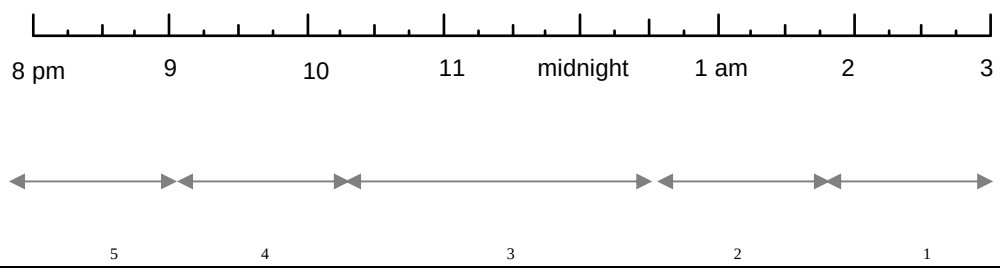
1. What time of day would you get up?

Please put a cross at the time closest to your best time.



2. What time of day would you go to bed?

Please put a cross at the time closest to your best time.



Waking Up In The Morning

3. You have to get up at a particular time in the morning. How much do you need to depend on the alarm clock to wake you up? *Please tick the box that applies to you.*

4 ☐ Not at all dependent | 3 ☐ Slightly dependent | 2 ☐ Fairly dependent | 1 ☐ Very dependent

4. If nothing is disturbing you (noise, light etc), how easy do you find it to get up in the morning?

1 ☐ Not at all easy | 2 ☐ Not very easy | 3 ☐ Fairly easy | 4 ☐ Very easy

5. How alert do you feel in the first half hour after waking up in the morning?

1 ☐ Not at all alert | 2 ☐ Slightly alert | 3 ☐ Fairly alert | 4 ☐ Very alert

6. How is your appetite in the first half hour after waking up in the morning?

1 ☐ Very poor | 2 ☐ Fairly poor | 3 ☐ Fairly good | 4 ☐ Very good

7. How tired do you feel in the first half hour after waking up in the morning?

1 ☐ Very tired | 2 ☐ Fairly tired | 3 ☐ Fairly refreshed | 4 ☐ Very refreshed

8. When there is nothing that you have to do tomorrow, what time do you go to bed, compared to your usual bedtime? *Please tick the box that applies to you*

4 ☐ Seldom or never later | 3 ☐ Less than 1 hour later | 2 ☐ 1-2 hours later | 1 ☐ More than 2 hours later

9. You and a friend have decided to do some physical exercise.

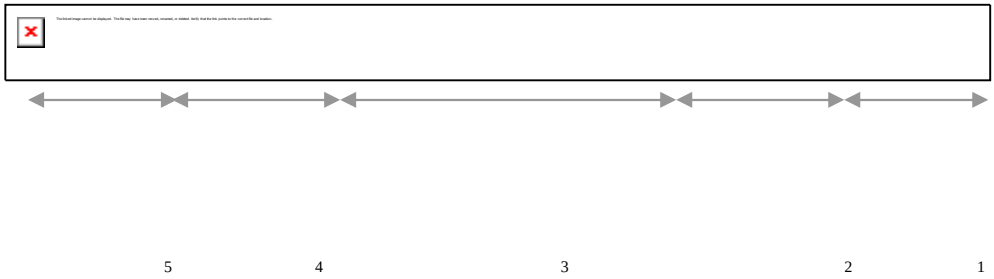
- **Your friend wants to train twice a week from <u>7-8 am</u>**
- **How well do you think your would perform at this time?**

Please tick the box that applies to you

4 ☐ Would be on good form	3 ☐ Would be on reasonable form	2 ☐ Would find it difficult	1 ☐ Would find it very difficult

10. What time in the evening do you start to feel tired and in need of sleep?

Please put a cross at the time that suits you best.



11. You want to do your best on an exhausting <u>mental</u> test that lasts 2 hours. Which one of these 4 test times would suit you best? *Please tick the box that is closest to your best time.*

6 ☐ 8-10am	4 ☐ 11am–1pm	2 ☐ 3-5pm	0 ☐ 7-9pm

12. If you went to bed at 11 pm, how tired would you normally be at that time?

Please tick the box that applies to you

0 ☐ Not at all tired	2 ☐ A little tired	3 ☐ Fairly tired	5 ☐ Very tired

13. If you go to bed a few hours later than usual, but don't have to get up at any special time in the morning, what is most likely to happen? *Please tick the box that applies to you*

4 ☐ I wake up at the usual time and <u>do not</u> fall back to sleep	3 ☐ I wake up at the usual time, then doze	2 ☐ I wake up at the usual time, then fall back to sleep	1 ☐ I do not wake up until later than usual

14. Imagine that you have to be at work, and stay alert, between 4-6 am. You don't have anything in particular to do the next day. Which of these strategies would suit you best? *Please tick the box that applies to you*

1 ☐ I would not go to bed until work was over	2 ☐ I would take a nap before work, then sleep after	3 ☐ I would take a good sleep before work, then nap after	4 ☐ I would take all my sleep before work

15. You have to do 2 hours of hard physical work. You are completely free to plan your day. When would you choose to do this work?

4 ☐ 8-10 am	3 ☐ 11 am – 1 pm	2 ☐ 3-5 pm	1 ☐ 7-9 pm

16. You and a friend have decided to do some physical exercise.

• Your friend wants to train between <u>10-11 pm</u>

• How well do you think you would perform at this time?

Please tick the box that applies to you

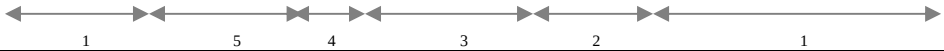
1 ☐ Would be on good form	2 ☐ Would be on reasonable form	3 ☐ Would find it difficult	4 ☐ Would find it very difficult

17. Imagine you can choose your own work hours. You have to work for 5 hours a day (including breaks). Your job is interesting, and you get paid for the amount of work you do. Which 5 hours <u>in a row</u> would you choose to work? *Please tick 6 boxes (i.e. start and end times and boxes in between)*

☐ ☐

12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12

midnight noon midnight



18. At what time of day do you feel your best? *Please tick 1 box to indicate your best time.*

☐ ☐

12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12

midnight noon midnight

19. You hear about "morning types" and "evening types". Which of the following types do you think you are? *Please tick the box that applies to you*

6 ☐ Definitely a morning type	4 ☐ More a morning type than an evening type	2 ☐ More an evening type than a morning type	0 ☐ Definitely an evening type

THANK-YOU FOR COMPLETING THIS QUESTIONNAIRE.

Please remember to bring this with you to the first session

Appendix C Data Distribution

Unfortunately, when it comes to statistical tests there is no one size fits all approach available for use. All parametric tests need to be appropriately matched to the data's distribution if type I and type II errors are to be minimized. In particular when modelling reaction times it is important that the distribution fits the right-hand tail (Ratcliff & Van Dongen, 2011). In instances where the data is an uncomfortable fit, consideration ought to be given to using non-parametric tests which do not rely on the data belonging to any particular distribution (Howell, 2007). The following two sections examine the data and associated distributions for fit so that the appropriate statistical tests could be selected without violating important test assumptions.

Discrete Data

Counts of microsleeps and attention lapses are discrete ordinal numbers that, when they originate from ecological studies, are often modelled using the Poisson distribution (Xie, He, & Goh, 2001). When the mean of a Poisson distribution is approximately 6 or more it approximates the normal distribution (Hogg & Tanis, 1993). The advantage this gives is that powerful parametric tests such as the t-test for dependent samples can be used. Accordingly, the frequency distribution of the count data was tested for departures from the normal distribution using Shapiro-Wilks' test of normality (See Table 0-1).

The results were significant across all four count measures indicating that significant departures from normality exist. An examination of data type, source and visual appearance was need to confirm whether those departures were a sufficient reason to exclude the use of 'statistical procedures requiring an underlying assumption of approximately normal'. The fitting of distributions should, according to Royston not depend solely on an arbitrarily assigned *p* value based only on shape (1991).

Accordingly, histograms of the count data were reviewed. They show that all four sets of data do not fit the normal distribution well. All are positively skewed (see Figure 0-1 below). There are signs of bimodality in the microsleep data and strong leptokurtic tendencies showing in the tracking and PVT tasks.

Therefore, taking into account the frequency distribution shapes, the fact that the data consisted of ecological counts, and the results of the Shapiro-Wilks test of normality, it was concluded that statistical tests reliant on an assumption of normality would be inappropriate for these data sets.

It was also evident in Figure 0-1 that there exist high counts of zeros and strong right hand tails, both of which are indications of over-dispersion. Over-dispersion, can make the use of statistical tools based on the Poisson distribution problematic. A key requirement of any Poisson process is that its sample mean should approximate its sample variance. When the sample variance is larger than the sample mean, the data is said to be over dispersed (Dean & Lawless, 1989; StatSoft, 2012). A failure to account for this over dispersion can result in Type I errors due to biased parameter estimates and thus lead to incorrect inferences (Lee, Wang, Scott, Yau, & McLachlan, 2006). As can be seen in Table 0-1, all bar the measure of microsleep

counts from the dual tracking task are over dispersed. This is particularly so for the attention lapse measures where the variance exceeds the mean by a factor of 34 or more.

Figure 0-1 Shown are histograms of the count data for microsleeps and attention lapses. Superimposed over the histograms is the expected normal distribution. All four measures show poor fits to the normal distribution. Evident are the high zero counts for the microsleep data. Also evident is the positive skew, and indications of over dispersion for all distributions.

Zero inflation is another form of over-dispersion, and typical of ecological data (Martin et al., 2005) the count of microsleeps in this study consisted of many zero values. A breakdown of the observations revels that of the 23 participants included in the analysis, 11 participants did not microsleep in either task, 2 did not microsleep in the tracking task and 7 did not microsleep in the dual task. Only three participants microslept in both tasks.

Zero inflation was tested using a Goodness of Fit test evaluated against a Chi-squared distribution (Xie et al., 2001). The result for the tracking task was significant $\chi 2_{1}$, (N=23) =52.76, $p < .001$ providing compelling evidence that the distribution of counts from the tracking task was zero-inflated. The goodness of fit test applied to the dual task was not significant ($\chi 2_{1}$, (N=23) =0.01, $p > .051$).

Table 0-1 Listed are shape characteristics for microsleep and attention lapse counts and tracking errors and reaction times. The results of the Shapiro-Wilks test of normality are included .

Measure	task	Mean	Var	Skewness	Kurtosis	Shapiro-Wilks W
Microsleep	tracking	2.3	22.1	2.6	6.8	$W = .55,\ p < .001$
	dual	0.2	0.2	1.5	0.2	$W = .51,\ p < .001$
Attention lapse	PVT	9.7	331.2	3.0	8.9	$W = .54,\ p < .001$
	dual	36.9	1253.2	1.4	1.0	$W = .75,\ p < .001$
tracking errors	tracking	20.6	17.0	0.35	-0.5	$W = .96,\ p = .552$
	dual	20.8	72.6	0.23	-0.8	$W = .96,\ p = .469$
Reaction times	PVT	329.8	2923.6	1.49	2.3	$W = .86,\ p = .004$
	dual	395.0	2963.7	0.72	0.2	$W = .93,\ p = .117$

As a consequence of the count data being positively skewed, leptokurtic, zero-inflated and over dispersed, it was determined that not only was it unsuitable for tests relying of an assumption of normality the data was also not ideally suited to parametric testing. Whilst it is possible to compensate for the over dispersion and zero-inflation using such models as Quasi-Poisson or Zero Inflated-Poisson (for example see Lee et al., 2006; Ver Hoef & Boveng, 2007; Xie et al., 2001) and while it may be possible to transform data to better fit a normal distribution (Norris & Aroian, 2004; O'Hara & Kotze, 2010) such procedures are complicated and not without controversy (Osborne & Overbay, 2004).

Continuous Data

Tracking errors, and reaction times, fall into the category of continuous ordinal and interval data. Histograms of these measures can be seen in Figure 0-2. These histograms show a much better fit with the expected normal distribution than did the count data. Nonetheless, the Shapiro-Wilk's test of normality was significant for reaction times in the PVT task measures (see Table 3-5), indicating that in that task, significant departures from normality exist.

The distribution of reaction times is well known for being positively skewed. However, unlike the count data, this departure was not considered sufficient to void tests that are robust to the assumption of normality.

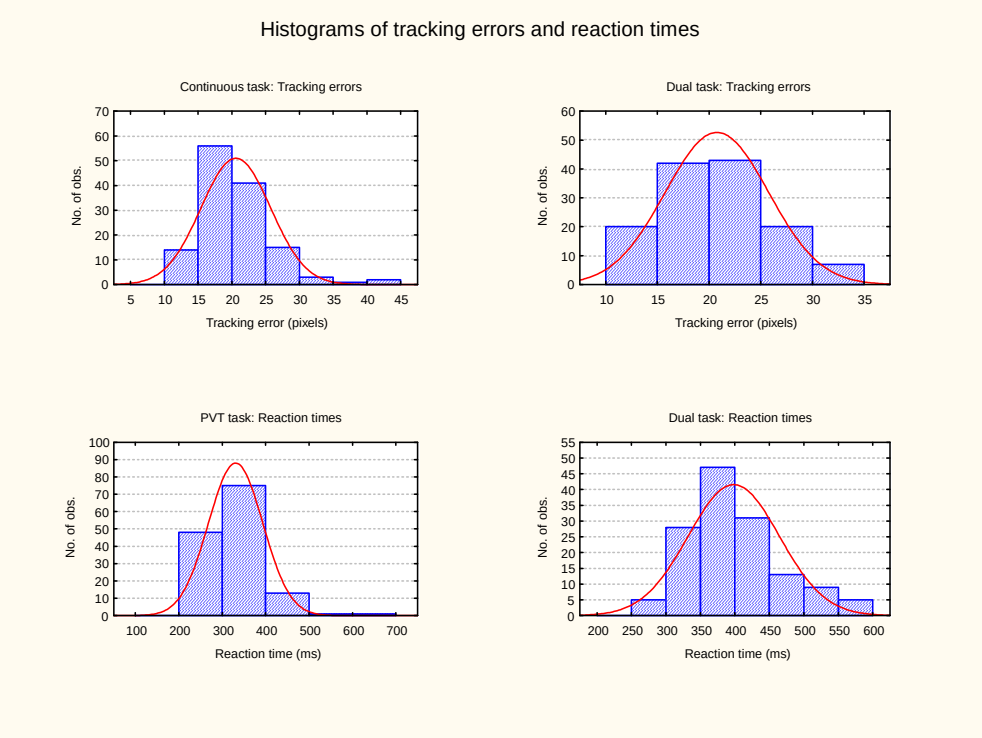


Figure 0-2 Represented by the columns are histograms of tracking errors and reaction times. The line indicates the expected normal distribution. Overall the fit to the normal distribution is more acceptable than the count data and many of the problems fitting the count data to a normal distribution shape have largely disappeared. However signs of a positive skew are still evident. Gone though is the over dispersion and these distributions are all unimodal, unlike that of the counts.

This data has in general, large sample sizes. The sample size for the tracking data is based on over 100,000 samples per participant per task, whilst the data from the reaction times was a more modest 265 samples per participant per task. Furthermore, the distributions are unimodal and although the data is limited to positive values (i.e., both the tracking errors and reaction times must be equal to or greater than zero) they do not show excessive positive skew nor do they show signs of over dispersion. Therefore, this continuous data will be analysed using parametric tests based on the normal distribution.

4.3.1.1.2 Notes to Table 3-6

Note 1: Differences in the observed counts of microsleeps and attention lapses per participant were analysed using the nonparametric Wilcoxon paired-sample signed-rank test. This is a test for the equality of central tendencies for matched pairs as is the Sign test but with better power (Bain & Engelhardt, 1992). Although the Wilcoxon tests a slightly different and broader hypothesis than the t-test, it is, according to Howell (2007), especially sensitive to population differences of location. It was chosen above the t-test because of its power advantage when the sample distribution is non-normal. Although the t test is reputed to be robust against non-normality and is purportedly more powerful than non-parametric tests of location (For example, Boneau, 1962) it has been argued that this advantage does not apply to the Wilcoxon Signed-

Ranks test when assumptions of normality are violated (Blair & Higgins, 1980; Bridge & Sawilowsky, 1999; Jones, 2006; Sawilowsky, 2005).

Note 2: The MANOVA was chosen because of its immunity to violations of the sphericity assumption. It is deemed to be a better approach (Howell, 2007) than compensating for sphericity violation by modify the F value that procedures such as the Greenhouse-Geisser and Huyn-Feldt do (Girden, 1992). In this study, sphericity could not be assumed for data relating to reaction times and tracking errors. Mauchly's test of sphericity indicated that with respect to tracking errors, the assumption of sphericity had been violated for both time ($\chi 2\ 14 = 63.0$, $p < .001$) and interaction of task and time ($\chi 2\ 14 = 38.5$, $p < .001$). Similarly, with respect to reaction times, sphericity was also violated for both time ($\chi 2\ 14 = 41.1$, $p < .001$) and interaction of task and time ($\chi 2\ 14 = 63.5$, $p < .001$).

Note 3: For correlations involving counts of microsleeps or attention lapses the non-parametric Spearman's ranked order test was used. Otherwise Pearson's product moment correlation test was applied.

The aligned-rank-transform-test (Wobbrock et al., 2011) was used to analyse the interaction between task and time for attention lapses. This non-parametric test is the equivalent of the ANOVA repeated-measures test. Whereas the Friedmans test can only cope with one factor, this test can cope with N factors.

The alignment of the response variable removes all effects from the response except for the one of interest. The aligned responses are then ranked and a full factorial ANOVA in run on the ranked responses, but only for the effect for which the responses were aligned to. In this study, we used Friedman's ANOVA for main effects and so the only effect of interest for this procedure was the Time on task interaction.

The residual for each response Y_{ij} = Y – cell mean (i.e., the mean of all residuals with the same factor level as the residual Y_{ij}

The estimated effect for the A×B interaction with response $Y_{ij} = A_iB_j - A_i - B_j + \mu$. (Where A_i = PVT task or dual task and B_j = five min time bin 1…6).

The aligned response $Y_{aligned}$ = residual + estimated effect

$= Y - \text{cell mean} + A_iB_j - A_i - B_j + \mu$.

The aligned response is ranked and then using the same factors as inputs plus the aligned response perform a separate ANOVA for each main effect of interaction. Interpret the results only for the factor or interaction that the response had been aligned and ranked for (Wobbrock et al., 2011).